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Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing the Functions of Headwater Slope Wetlands on the Mississippi and Alabama Coastal Plains

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Thomas H. Roberts, and Cindy Henderson

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ABSTRACT: The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence. This Regional Guidebook (a) characterizes the Headwater Slope wetlands in southern Mississippi and Alabama, (b) describes and provides the rationale used to select functions for the Headwater Slope wetland subclass, (c) describes model variables and metrics, (d) describes the development of assessment models, (e) provides data from reference wetlands and documents their use in calibrating model variables and assessment models, and (f) outlines protocols for applying the functional indices to the assessment of wetland functions.

Corps of Engineers Research Report Summary, August 2007

Assessing Wetland Functions

Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing the Functions of Headwater Slope Wetlands on the Mississippi and Alabama Coastal Plains (ERDC/EL TR-07-9)

ISSUE: Section 404 of the Clean Water Act directs the U.S. Army Corps of Engineers to administer a regulatory program for permitting the discharge of dredged or fill material in the "waters of the United States." As part of the permit review process, the impact of discharging dredged or fill material on wetland functions must be assessed. On 16 August 1996, a National Action Plan to Implement the Hydrogeomorphic Approach (NAP) for developing Regional Guidebooks to assess wetland functions was published. This report is one of a series of Regional Guidebooks that will be published in accordance with the National Action Plan.

RESEARCH OBJECTIVE: The objective of this research was to develop a Regional Guidebook for applying the Hydrogeomorphic Approach to Headwater Slope in southern Mississippi and Alabama in a planning and ecosystem restoration context.

SUMMARY: This Regional Guidebook characterizes the Headwater Slope wetlands in southern Mississippi and Alabama, describes and provides the rationale used to select functions for the Headwater Slope wetland subclass, describes model variables and metrics, describes the development of assessment models, provides data from reference wetlands and documents their use in calibrating model variables and assessment models, and outlines protocols for applying the functional indices to the assessment of wetland functions.

AVAILABILITY OF REPORT: The report is available at the following Web sites: http://el.erdc.usace.army.mil/wetlands/pubs.html, http://el.erdc.usace.army.mil/emrrp/techtran.html or http://itl.erdc.usace.army.mil/library/.

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Preface

This work was performed by the U.S. Army Engineer Research and Development Center (ERDC) under a Cooperative Research and Development Agreement with the Mississippi Department of Marine Resources (MDMR). Funding was provided by a grant from the U.S. Environmental Protection Agency, Region 4, to MDMR.

This report was prepared by Chris V. Noble and Dr. James S. Wakeley, Environmental Laboratory (EL), ERDC; Dr. Thomas H. Roberts, Tennessee Technological University, Cookeville; and Cindy Henderson, MDMR. This guidebook was developed in cooperation with an Assessment Team (A-Team) of experts familiar with Headwater Slope wetlands in Alabama and Mississippi. The following A-Team members made major contributions to the development of this guidebook: Garth Crow and Steve Threlkeld, Alabama Department of Conservation and Natural Resources; Paul Rodrigue, U.S. Department of Agriculture Natural Resources Conservation Service; and Darrell Evans, ERDC. In addition, the authors are grateful to the following A-Team members who contributed their time and expertise at team meetings and/or participated in field sampling of reference wetlands: Jennifer Buchanan, Rachel Culp, Franklin Leach, and Mark Woodrey, MDMR; Florance Watson, Mississippi Department of Environmental Quality; Leslie Turney and Randy Shaneyfelt, Alabama Department of Environmental Management; Mark Peterson, University of Southern Mississippi, Gulf Coast Research Laboratory; Munther Sahawneh, U.S. Army Corps of Engineers, Mobile District; and Patric Harper, Darren LeBlanc, and Paul Necaise, U.S. Fish and Wildlife Service.

While not directly involved with the development of this guidebook, A. Jason Hill and Dr. Vincent S. Neary, Tennessee Technological University, contributed ideas and concepts through their involvement in currently unpublished guidebooks.

This work was performed under the general supervision of Dr. Morris Mauney, Jr., Chief, Wetlands and Coastal Ecology Branch, EL; Dr. David J. Tazik, Chief, Ecosystem Evaluation and Engineering Division, EL; and Dr. Elizabeth C. Fleming, Director, EL.

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1 Introduction

Background

The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review process to consider alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements, and monitor the success of mitigation projects. However, a variety of other potential applications for the approach have been identified, including determining minimal effects under the Food Security Act, designing wetland restoration projects, and managing wetlands.

On 16 August 1996, a National Action Plan (NAP) to implement the Hydrogeomorphic Approach was adopted (Federal Register 1997). The NAP was developed cooperatively by a National Interagency Implementation Team consisting of the U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (USEPA), Natural Resources Conservation Service (NRCS), Federal Highway Administration (FHWA), and U.S. Fish and Wildlife Service (USFWS). The NAP outlines a strategy to promote the development of Regional Guidebooks for assessing the functions of regional wetland subclasses using the HGM Approach; provides guidelines and a set of tasks required to develop Regional Guidebooks; and solicits the cooperation and participation of Federal, State, and local agencies, academia, and the private sector in this effort.

The sequence of tasks necessary to develop a Regional Guidebook outlined in the NAP was used to develop this Regional Guidebook (see the section "Development Phase" in Chapter 2). An initial workshop was held in Biloxi, MS, on 28-29 May 2003. Subsequent meetings were held 24-25 July and 16-17 October 2003. These workshops were attended by hydrologists, soil scientists, wildlife biologists, and plant ecologists from the public and academic sectors with knowledge of the headwater wetland ecosystem. Based on the results of the workshops, one regional wetland subclass was defined and characterized, a reference domain was defined, wetland functions were selected, model variables were identified, and conceptual assessment models were developed. Subsequently, fieldwork was conducted to collect data from reference wetlands. These data were used to revise and calibrate the conceptual assessment models.

Objectives

The objectives of this Regional Guidebook are to (a) characterize the Headwater Slope wetlands in southern Alabama and Mississippi, (b) describe and provide the rationale used to select functions for the Headwater Slope wetland subclass, (c) describe model variables and metrics, (d) describe the development of assessment models, (e) provide data from reference wetlands and document their use in calibrating model variables and assessment models, and (f) outline the necessary protocols for applying the functional indices to the assessment of wetland functions.

Scope

This guidebook is organized in the following manner. Chapter 1 provides the background, objectives, and organization of the guidebook. Chapter 2 summarizes the major components of the HGM Approach and the development and application phases required to implement the approach. Chapter 3 characterizes the Headwater Slope wetland subclass in southern Alabama and Mississippi in terms of geographical extent, climate, geomorphic setting, hydrology, vegetation, soils, and other factors that influence wetland function. Chapter 4 discusses each of the wetland functions, model variables, and functional indices. This discussion includes a definition of each function; a quantitative, independent measure of the function for the purposes of model validation; a description of the wetland ecosystem and landscape characteristics that influence the function; a definition and description of model variables used to represent these characteristics in the assessment model; a discussion of the assessment model used to derive the functional index; and an explanation of the rationale used to calibrate the index with reference wetland data. Chapter 5 outlines the steps in the assessment protocol for conducting a functional assessment of Headwater Slope wetlands in southern Alabama and Mississippi. Appendix A presents a Glossary. Appendix B contains supplementary information on model variables.

While it is possible to assess the functions of Headwater Slope wetlands in southern Alabama or Mississippi using only the information contained in Chapter 5, it is suggested that potential users familiarize themselves with the information in Chapters 2-4 prior to conducting an assessment.

2 Overview of the Hydrogeomorphic Approach

As indicated in Chapter 1, the HGM Approach is a collection of concepts and methods for developing functional indices and using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The HGM Approach includes four integral components: (a) the HGM classification, (b) reference wetlands, (c) assessment models/functional indices, and (d) assessment protocols. During the development phase of the HGM Approach, these four components are integrated into a Regional Guidebook for assessing the functions of a regional wetland subclass. Subsequently, during the application phase, end users, following the assessment protocols outlined in the Regional Guidebook, assess the functional capacity of selected wetlands. Each of the components of the HGM Approach and the development and application phases are discussed in this chapter. More extensive discussions can be found in Brinson (1993; 1995a, b), Brinson et al. (1995, 1996, 1998), Smith et al. (1995), Hauer and Smith (1998), Smith (2001), Smith and Wakeley (2001), and Wakeley and Smith (2001).

Hydrogeomorphic Classification

Wetland ecosystems share a number of features including relatively long periods of inundation or saturation, hydrophytic vegetation, and hydric soils. In spite of these common attributes, wetlands occur under a wide range of climatic, geologic, and physiographic situations and exhibit a wide variety of physical, chemical, and biological characteristics and processes (Cowardin et al. 1979; Semeniuk 1987; Ferren et al. 1996a, 1996b, 1996c; Mitsch and Gosselink 2000). The variability of wetlands makes it challenging to develop assessment methods that are both accurate (i.e., sensitive to significant changes in function) and practical (i.e., can be completed in the relatively short time frame available for conducting assessments). Existing generic methods designed to assess multiple wetland types throughout the United States are relatively rapid, but lack the resolution necessary to detect significant changes in function. However, one way to achieve an appropriate level of resolution within the available time frame is to reduce the level of variability exhibited by the wetlands being considered (Smith et al. 1995).

The HGM Classification was developed specifically to accomplish this task (Brinson 1993). It identifies groups of wetlands that function similarly using three criteria that fundamentally influence how wetlands function: geomorphic setting, water source, and hydrodynamics. Geomorphic setting refers to the landform and position of the wetland in the landscape. Water source refers to the primary water source in the wetland such as precipitation, overbank floodwater, or groundwater. Hydrodynamics refers to the level of energy and the direction that water moves in the wetland. Based on these three classification criteria, any number of functional wetland groups can be identified at different spatial or temporal scales. For example, at a continental scale, Brinson (1993) identified five hydrogeomorphic wetland classes. These were later expanded to the seven classes described in Table 1 (Smith et al. 1995). In many cases, the level of variability in wetlands encompassed by a continental scale hydrogeomorphic class is still too great to allow development of assessment models that can be rapidly applied while being sensitive enough to detect changes in function at a level of resolution appropriate to the Section 404 review process. For example, at a continental geographic scale the depression class includes wetland ecosystems in different regions as diverse as California vernal pools (Zedler 1987), prairie potholes in North and South Dakota (Hubbard 1988; Kantrud et al. 1989), playa lakes in the high plains of Texas (Bolen et al. 1989), kettles in New England, and cypress domes in Florida (Ewel 1984; Kurz and Wagner 1953).

To reduce both inter- and intraregional variability, the three classification criteria are applied at a smaller, regional geographic scale to identify regional wetland subclasses. In many parts of the country, existing wetland classifications can serve as a starting point for identifying these regional subclasses (Stewart and Kantrud 1971; Golet and Larson 1974; Wharton et al. 1982; Ferren et al. 1996a, 1996b, 1996c). Regional subclasses, like the continental classes, are distinguished on the basis of geomorphic setting, water source, and hydrodynamics. In addition, certain ecosystem or landscape characteristics may also be useful for distinguishing regional subclasses in certain regions. For example, depressional subclasses might be based on water source (i.e., groundwater versus surface water), or the degree of connection between the wetland and other surface waters (i.e., the flow of surface water in or out of the depression through defined channels). Tidal fringe subclasses might be based on salinity gradients (Shafer and Yozzo 1998). Slope subclasses might be based on the degree of slope, landscape position, the source of water (i.e., throughflow versus groundwater), or other factors. Riverine subclasses might be based on water source, position in the watershed, stream order, watershed size, channel gradient, or floodplain width. Examples of potential regional subclasses are shown in Table 2, adapted from Smith et al. (1995), and Rheinhardt et al. (1997).

Regional Guidebooks include a thorough characterization of the regional wetland subclass in terms of its geomorphic setting, water source, hydrodynamics, vegetation, soil, and other features that were taken into consideration during the classification process.

Table 1
Hydrogeomorphic Wetland Classes at the Continental Scale

HGM Wetland Class	Definition
Depression	Depression wetlands occur in topographic depressions (i.e., closed elevation contours) that allow the accumulation of surface water. Depression wetlands may have any combination of inlets and outlets, or lack them completely. Potential water sources are precipitation, overland flow, streams, or groundwater flow from adjacent uplands. The predominant direction of flow is from the higher elevations toward the center of the depression. The predominant hydrodynamics are vertical fluctuations that may occur over a range of time, from a few days to many months. Depression wetlands may lose water through evapotranspiration, intermittent or perennial outlets, or recharge to groundwater. Prairie potholes, playa lakes, and cypress domes are common examples of depression wetlands.
Tidal Fringe	Tidal fringe wetlands occur along coasts and estuaries and are under the influence of sea level. They intergrade landward with riverine wetlands where tidal current diminishes and riverflow becomes the dominant water source. Additional water sources may be groundwater discharge and precipitation. Because tidal fringe wetlands are frequently flooded and water table elevations are controlled mainly by sea surface elevation, tidal fringe wetlands seldom dry for significant periods. Tidal fringe wetlands lose water by tidal exchange, by overland flow to tidal creek channels, and by evapotranspiration. Organic matter normally accumulates in higher elevation marsh areas where flooding is less frequent and the wetlands are isolated from shoreline wave erosion by intervening areas of low marsh or dunes. *Spartina alterniflora* salt marshes are a common example of tidal fringe wetlands.
Lacustrine Fringe	Lacustrine fringe wetlands are adjacent to lakes where the water elevation of the lake maintains the water table in the wetland. Additional sources of water are precipitation and groundwater discharge, the latter dominating where lacustrine fringe wetlands intergrade with uplands or slope wetlands. Surface water flow is bidirectional. Lacustrine wetlands lose water by evapotranspiration and by flow returning to the lake after flooding. Organic matter may accumulate in areas sufficiently protected from shoreline wave erosion. Unimpounded marshes bordering the Great Lakes are an example of lacustrine fringe wetlands.
Slope	Slope wetlands are found in association with the discharge of groundwater to the land surface or on sites with saturated overland flow and no channel formation. They normally occur on slightly to steeply sloping land. The predominant source of water is groundwater or interflow discharging at the land surface. Precipitation is often a secondary contributing source of water. Hydrodynamics are dominated by downslope unidirectional water flow. Slope wetlands can occur in nearly flat landscapes if groundwater discharge is a dominant source to the wetland surface. Slope wetlands lose water primarily by saturated subsurface flows, surface flows, and evapotranspiration. They may develop channels, but the channels serve only to convey water away from the slope wetland. Slope wetlands are distinguished from depression wetlands by the lack of a closed topographic depression and the predominance of the groundwater/interflow water source. Fens are a common example of slope wetlands.
Mineral Soil Flats	Mineral soil flats are most common on interfluves, extensive relic lake bottoms, or large alluvial terraces where the main source of water is precipitation. They receive virtually no groundwater discharge, which distinguishes them from depressions and slopes. Dominant hydrodynamics are vertical fluctuations. Mineral soil flats lose water by evapotranspiration, overland flow, and seepage to underlying groundwater. They are distinguished from flat non-wetland areas by their poor vertical drainage caused by impermeable layers (e.g., hardpans), slow lateral drainage, and low hydraulic gradients. Pine flatwoods with hydric soils are an example of mineral soil flat wetlands.
Organic Soil Flats	Organic soil flats, or extensive peatlands, differ from mineral soil flats in part because their elevation and topography are controlled by vertical accretion of organic matter. They occur commonly on flat interfluves, but may also be located where depressions have become filled with peat to form a relatively large flat surface. Water source is dominated by precipitation, while water loss is by overland flow and seepage to underlying groundwater. They occur in relatively humid climates. Raised bogs share many of these characteristics but may be considered a separate class because of their convex upward form and distinct edaphic conditions for plants. Portions of the Everglades and northern Minnesota peatlands are examples of organic soil flat wetlands.
Riverine	Riverine wetlands occur in floodplains and riparian corridors in association with stream channels. Dominant water sources are overbank or backwater flow from the channel. Additional sources may be interflow, overland flow from adjacent uplands, tributary inflow, and precipitation. When overbank flow occurs, surface flows down the floodplain may dominate hydrodynamics. In headwaters, riverine wetlands often intergrade with slopes, depressions, flats, or uplands as the channel system becomes indistinct. Riverine wetlands lose surface water via the return of floodwater to the channel after flooding and through surface flow to the channel during rainfall events. They lose subsurface water by discharge to the channel, movement to deeper groundwater, and evapotranspiration. Bottomland hardwood forests on floodplains are examples of riverine wetlands.

Table 2
Potential Regional Wetland Subclasses in Relation to Geomorphic Setting, Dominant Water Source, and Hydrodynamics

Geomorphic Setting	Dominant Water Source	Dominant Hydrodynamics	Potential Regional Wetland Subclasses	
			Eastern USA	Western USA/Alaska
Depression	Groundwater or interflow	Vertical	Prairie potholes, marshes, Carolina bays	California vernal pools
Fringe (tidal)	Ocean	Bidirectional, horizontal	Chesapeake Bay and Gulf of Mexico tidal marshes	San Francisco Bay marshes
Fringe (lacustrine)	Lake	Bidirectional, horizontal	Great Lakes marshes	Flathead Lake marshes
Slope	Groundwater	Unidirectional, horizontal	Headwater wetlands	Avalanche chutes
Flat (mineral soil)	Precipitation	Vertical	Wet pine flatwoods	Large playas
Flat (organic soil)	Precipitation	Vertical	Peat bogs, portions of Everglades	Peatlands over permafrost
Riverine	Overbank flow from channels	Unidirectional, horizontal	Bottomland hardwood forests	Riparian wetlands

Note: Adapted from Smith et al. 1995 and Rheinhardt et al. 1997.

Reference Wetlands

Reference wetlands are wetland sites selected to represent the range of variability that occurs in a regional wetland subclass as a result of natural processes and disturbance (e.g., succession, channel migration, fire, erosion, and sedimentation) as well as cultural alteration. The reference domain is the geographic area occupied by the reference wetlands (Smith et al. 1995). Ideally, the geographic extent of the reference domain will mirror the geographic area encompassed by the regional wetland subclass; however, this is not always possible due to time and resource constraints.

Reference wetlands serve several purposes. First, they establish a basis for defining what constitutes a characteristic and sustainable level of function across the suite of functions selected for a regional wetland subclass. Second, they establish the range and variability of conditions exhibited by model variables and provide the data necessary for calibrating model variables and assessment models. Finally, they provide a concrete physical representation of wetland ecosystems that can be observed and measured.

Reference standard wetlands are the subset of reference wetlands that perform the suite of functions selected for the regional subclass at a level that is characteristic in the least altered wetland sites in the least altered landscapes. Table 3 outlines the terms used by the HGM Approach in the context of reference wetlands.

Table 3 Reference Wetland Terms and Definitions	
Term	**Definition**
Reference domain	The geographic area from which reference wetlands representing the regional wetland subclass are selected (Smith et al. 1995).
Reference wetlands	A group of wetlands that encompass the known range of variability in the regional wetland subclass resulting from natural processes and disturbance and from human alterations.
Reference standard wetlands	The subset of reference wetlands that perform a representative suite of functions at a level that is both sustainable and characteristic of the least human-altered wetland sites in the least human-altered landscapes. By definition, functional capacity indices for all functions in reference standard wetlands are assigned a value of 1.0.
Reference standard wetland variable condition	The range of conditions exhibited by model variables in reference standard wetlands. By definition, reference standard conditions receive a variable subindex score of 1.0.
Site potential (mitigation project context)	The highest level of function possible, given local constraints of disturbance history, land use, or other factors. Site potential may be less than or equal to the levels of function in reference standard wetlands of the regional wetland subclass.
Project target (mitigation project context)	The level of function identified or negotiated for a restoration or creation project.
Project standards (mitigation context)	Performance criteria and/or specifications used to guide the restoration or creation activities toward the project target. Project standards should specify reasonable contingency measures if the project target is not being achieved.

Assessment Models and Functional Indices

In the HGM Approach, an assessment model is a simple representation of a function performed by a wetland ecosystem. It defines the relationship between one or more characteristics or processes of the wetland ecosystem. Functional capacity is simply the ability of a wetland to perform a function compared to the level of performance in reference standard wetlands.

Model variables represent the characteristics of the wetland ecosystem and surrounding landscape that influence the capacity of a wetland ecosystem to perform a function. Model variables are ecological quantities that consist of five components (Schneider 1994): (a) a name, (b) a symbol, (c) a measure of the variable and procedural statements for quantifying or qualifying the measure directly or calculating it from other measures, (d) a set of variables (i.e., numbers, categories, or numerical estimates (Leibowitz and Hyman 1997)) that are generated by applying the procedural statement, and (e) units on the appropriate measurement scale. Table 4 provides several examples.

Table 4 Components of a Model Variable			
Name (Symbol)	**Measure / Procedural Statement**	**Resulting Values**	**Units (Scale)**
Number of canopy trees (V_{CTDEN})	Average number of canopy trees	0 to $\geq$20	unitless
Canopy tree diameter (V_{CTD})	Average diameter at breast height (dbh) of canopy trees	0.0 to >100	centimeters
Soil detritus ($V_{DETRITUS}$)	Percentage cover of soil detritus	0 to 100	percent

Model variables occur in a variety of states or conditions in reference wetlands. The state or condition of the variable is denoted by the value of the measure of the variable. For example, percentage soil detritus, the measure of the percentage cover of soil detritus, could be large or small. Based on its condition (i.e., value of the metric), a model variable is assigned a variable subindex. When the condition of a variable is within the range of conditions exhibited by reference standard wetlands, a variable subindex of 1.0 is assigned. As the condition deviates from the reference standard condition (i.e., the range of conditions within which the variable occurs in reference standard wetlands), the variable subindex is assigned based on the defined relationship between model variable condition and functional capacity. As the condition of a variable deviates from the conditions exhibited in reference standard wetlands, it receives a progressively lower subindex reflecting its decreasing contribution to functional capacity. In some cases, the variable subindex drops to zero. For example, when the percentage cover of soil detritus is 95 percent or greater, the subindex for percentage herbaceous ground cover is one. As the percent cover falls below 95 percent, the variable subindex score decreases on a linear scale to zero.

Model variables are combined in an assessment model to produce a Functional Capacity Index (FCI) that ranges from 0.0 to 1.0. The FCI is a measure of the functional capacity of a wetland relative to reference standard wetlands in the reference domain. Wetlands with an FCI of 1.0 perform the function at a level characteristic of reference standard wetlands. As the FCI decreases, it indicates that the capacity of the wetland to perform the function is less than that characteristic of reference standard wetlands.

Assessment Protocol

The final component of the HGM Approach is the assessment protocol. The assessment protocol is a series of tasks, along with specific instructions, that allow the end user to assess the functions of a particular wetland area using the functional indices in the Regional Guidebook. The first task is characterization, which involves describing the wetland ecosystem and the surrounding landscape, describing the proposed project and its potential impacts, and identifying the wetland areas to be assessed. The second task is collecting the field data for model variables. The final task is analysis, which involves calculation of functional indices.

Development Phase

The Development Phase of the HGM Approach is ideally carried out by an interdisciplinary team of experts known as the Assessment Team, or A-Team. The product of the Development Phase is a Regional Guidebook for assessing the functions of a specific regional wetland subclass (Figure 1). In developing a Regional Guidebook, the A-Team will complete the following major tasks. After organization and training, the first task of the A-Team is to classify the wetlands within the region of interest into regional wetland subclasses using the principles and criteria of the HGM Classification (Brinson 1993; Smith et al. 1995). Next,

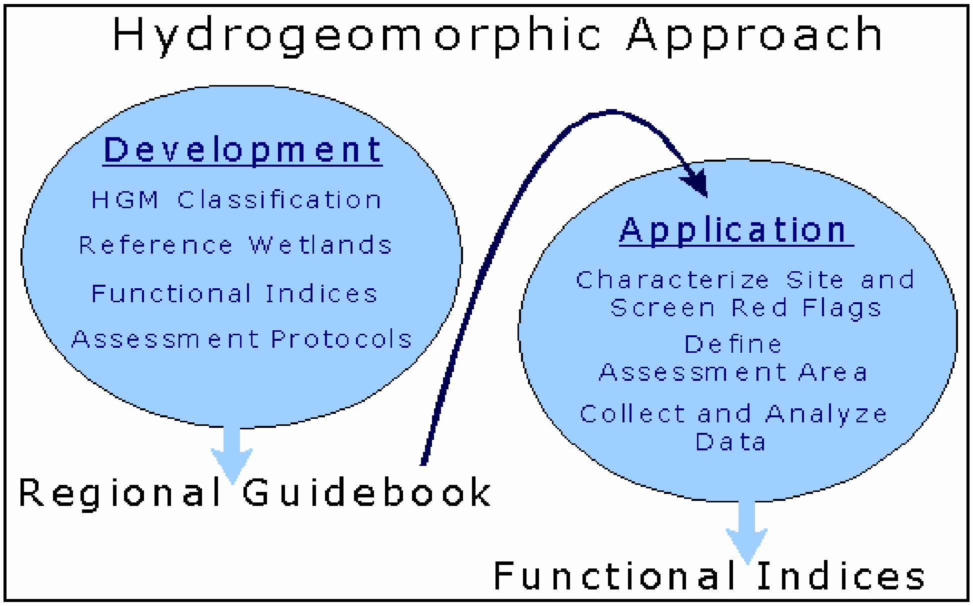

Figure 1. Development and application phases of the HGM Approach

focusing on the specific regional wetland subclasses selected, the A-Team develops an ecological characterization or functional profile of the subclass. The A-Team identifies the important wetland functions, conceptualizes assessment models, identifies model variables to represent the characteristics and processes that influence each function, and defines metrics for quantifying model variables. Next, reference wetlands are identified to represent the range of variability exhibited by the regional subclass. Field data are collected from the reference wetlands and used to calibrate model variables and verify the conceptual assessment models. Finally, the A-Team develops the assessment protocols necessary for regulators, managers, consultants, and other end users to apply the indices to the assessment of wetland functions. The following list provides the detailed steps involved in this general sequence:

Task 1: Organize the A-Team.

a. Identify A-Team members.

b. Train A-Team in the HGM Approach.

Task 2: Select and Characterize Regional Wetland Subclasses.

a. Identify/prioritize wetland subclasses.

b. Select regional wetland subclass and define reference domain.

c. Initiate literature review.

d. Develop preliminary characterization of regional wetland subclasses.

e. Identify and define wetland functions.

Task 3: Select Model Variables and Metrics and Construct Conceptual Assessment Models.

a. Review existing assessment models.

b. Identify model variables and metrics.

c. Define initial relationship between model variables and functional capacity.

d. Construct conceptual assessment models for deriving FCIs.

e. Complete Precalibrated Draft Regional Guidebook (PDRG).

Task 4: Conduct Peer Review of PDRG.

a. Distribute PDRG to peer reviewers.

b. Conduct interdisciplinary, interagency workshop of PDRG.

c. Revise PDRG to reflect peer review recommendations.

d. Distribute revised PDRG to peer reviewers for comment.

e. Incorporate final comments from peer reviewers on revisions into PDRG.

Task 5: Identify and Collect Data from Reference Wetlands.

a. Identify reference wetland field sites.

b. Collect data from reference wetland field sites.

c. Analyze reference wetland data.

Task 6: Calibrate and Field Test Assessment Models.

a. Calibrate model variables using reference wetland data.

b. Verify and validate (optional) assessment models.

c. Field test assessment models for repeatability and accuracy.

d. Revise PDRG based on calibration, verification, validation (optional), and field testing results into a Calibrated Draft Regional Guidebook (CDRG).

Task 7: Conduct Peer Review and Field Test of CDRG.

a. Distribute CDRG to peer reviewers.

b. Field test CDRG.

c. Revise CDRG to reflect peer review and field test recommendations.

d. Distribute CDRG to peer reviewers for final comment on revisions.

e. Incorporate peer reviewers' final comments on revisions.

f. Publish Operational Draft Regional Guidebook (ODRG).

Task 8: Technology Transfer.

a. Train end users in the use of the ODRG.

b. Provide continuing technical assistance to end users of the ODRG.

Application Phase

The Application Phase involves two steps. The first is using the assessment protocols outlined in the Regional Guidebook to complete the following tasks (Figure 1).

a. Define assessment objectives.

b. Characterize the project site.

c. Screen for red flags.

d. Define the Wetland Assessment Area.

e. Collect field data.

f. Analyze field data.

The second step involves applying the results of the assessment, the FCI, to the appropriate decision-making process of the permit review sequence, such as alternatives analysis, minimization, assessment of unavoidable impacts, determination of compensatory mitigation, design and monitoring of mitigation, comparison of wetland management alternatives or results, determination of restoration potential, or identification of acquisition or mitigation sites.

3 Characterization of Headwater Slope Wetlands on the Coastal Plains of Alabama and Mississippi

Regional Wetland Subclass and Reference Domain

This Regional Guidebook was developed to assess the functions of Headwater Slope wetlands on the Coastal Plains of Alabama and Mississippi. Within the reference domain, Headwater Slope wetlands occur primarily as linear drainages within a flat or rolling upland landscape (Figure 2). For the purpose of this guidebook, the subclass is defined as the wetlands in headwater areas above and including first-order streams, in which groundwater is the primary hydrologic input (Figure 3). The combination of landscape position and dominance of groundwater hydrology places these wetlands in the slope HGM class. Other names used to refer to wetlands in the regional subclass include bayheads, bay galls, springheads, and steepheads.

Development of this guidebook was initiated in part to meet the needs of Federal and State agencies for a procedure to assess existing and potential wetland mitigation sites in the southern counties of Alabama and Mississippi. Thus, the reference domain (i.e., the area in which this guidebook is applicable) is bounded to the west by the Pearl River in Mississippi and to the east by the Perdido River and a northward extension of the Escambia County line in Alabama (Figure 4). To the north, the reference domain extends to the northern limit of the Southern Pine Plains and Hills ecoregion (Griffith et al. 2001; Chapman et al. 2004).

The *potential* reference domain (i.e., the maximum geographic extent of the wetland subclass) (Smith et al. 1995) includes much of the outer Coastal Plain from Maryland to Texas, within the range of the several species of “bay” trees that typify the wetland subclass. However, the models in this guidebook were calibrated using data from reference wetlands in southern Mississippi and Alabama. These models may be applicable to Headwater Slope wetlands located elsewhere in the potential reference domain. Persons wishing to apply the

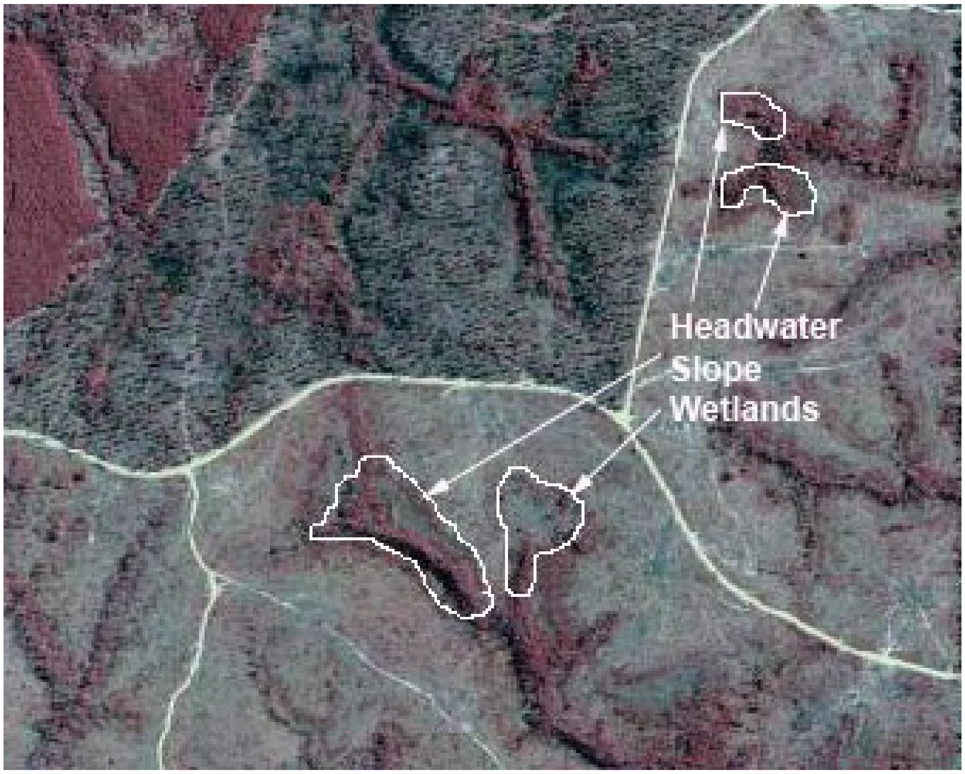

Figure 2. Aerial photograph showing four Headwater Slope wetlands in a flat to rolling Coastal Plain landscape

Figure 3. Example of a Headwater Slope wetland surrounding a first-order stream. The Headwater Slope wetland subclass does not include floodplain wetlands

Figure 4. Map of the reference domain in southern Mississippi and Alabama showing counties, major cities, and highways

models in other areas, however, should verify that existing reference data adequately describe local conditions. If not, additional reference data should be collected and used to revise the plant lists and recalibrate the subindex graphs.

Characterization of the Regional Subclass

Physiography and geology

The Coastal Plain is one of eight physiographic divisions described by Fenneman (1938) and consists of the broad, low-lying area along the immediate coastline extending from New England southward along the Atlantic Ocean and westward along the Gulf of Mexico to Texas and Mexico. In the Southeast, the Coastal Plain averages 100 to 200 miles (160 to 320 km) wide and is bordered to the interior by a highland area known as the Piedmont. The boundary separating these physiographic provinces is a relatively abrupt rise called the Fall Line. The Coastal Plain is flat to gently sloping; local relief generally is less than 100 ft

(30 m) near the coast, but can reach 600 ft (180 m) near the Fall Line (Bailey 1995). Marshes, swamps, and low-gradient streams and rivers are common. Rivers in the Gulf Coastal Plain, including the Alabama, Tombigbee, Pearl, and others, drain southward to the Gulf of Mexico.

The Coastal Plain is the inner portion of the Continental Shelf that has been covered by shallow seas periodically since the Mesozoic era, as evidenced by the various types of sedimentary deposits of Cretaceous age and younger that underlie it. During the most recent ice ages, the entire Continental Shelf was exposed because vast volumes of the earth's water were tied up in glaciers and the polar ice caps. As the ice ages ended, meltwater inundated the outer portion of the Continental Shelf while the slightly higher inner portion (i.e., the Coastal Plain) has remained exposed for approximately the past 10,000 years.

The Coastal Plain has been subjected to repeated differential movements that have resulted in a series of highs and intervening sags in the basement rock surface and overlying sediments along the entire coastline (Cederstrom et al. 1979). Cederstrom et al. (1979) described the underlying sediments of the Coastal Plain as unconsolidated clay, sand, and gravel, and unconsolidated or semiconsolidated limestone. The deposits, which range in age from Cretaceous to Holocene, form an arch that extends from Virginia through the Carolinas, Georgia, and Alabama into eastern Mississippi. The deposits are thin near the Fall Line and thicken toward the coast.

Generally, the Coastal Plain beds have a gentle slope or dip seaward. Each formation has been overlapped by the next younger formation, and their eroded edges are now exposed in a succession of older (inland) to younger (seaward) arcuate belts. Formations are rarely uniform laterally or downdip. Nearshore, sandy, deltaic continental sediments thicken downdip and grade into deeper water silty or limy marine deposits. Laterally, sediments also may change in proportion of sand and clay, or may become limy. Sandy terrace deposits were superimposed upon the older formations during the Pleistocene Epoch (Cederstrom et al. 1979). The current form of the Coastal Plain from Chesapeake Bay to eastern Texas largely is the result of sediment deposition, both alluvial and marine, from the adjacent eroding mountains and Piedmont. It has been sculpted by hydrologic and fluvial geomorphologic processes that vary in their effect in response to changes in sea level and climate (Hupp 2000).

Climate

The climate within the reference domain is characterized by hot humid summers and mild winters (Bailey 1995). Average annual temperatures range from 60 to 70 ºF (15 to 21 ºC), with summer temperatures averaging in the 70s and winter temperatures in the 50s. Precipitation averages 50 to 70 in. (125 to 180 cm) annually and is fairly evenly distributed throughout the year. There are slight peaks in early spring and midsummer, the latter due mainly to frequent thunderstorms produced by southerly winds that bring in moisture from the Gulf of Mexico. Along the coast, 5 in. (13 cm) or more of rain may fall in a 24-hour period. In Mobile, AL, more than 13 in. (33 cm) of rain fell in one day in April 1955. Tropical storms or hurricanes occasionally strike coastal areas and, when they occur, rainfall can be very heavy for brief periods. In addition, storm surges

in combination with local runoff can cause flooding of headwaters and small streams that empty directly into tidal systems. Overall, this climate provides a water surplus in the reference domain, with precipitation exceeding potential evapotranspiration for much of the year. However, water deficits (evapotranspiration exceeds precipitation) usually occur in late spring (May and early June) and late summer (August and September). The growing season based on soil temperatures above 41 ºF (5 ºC) at 20-in. (51-cm) depth (U.S. Department of Agriculture (USDA) Natural Resources Conservation Service 1999) is year-round throughout the reference domain, although most crops are grown from April through September. Frost occurs nearly every winter, but snow is rare.

Geomorphic setting

The Headwater Slope subclass is defined in this guidebook as occurring in headwater areas above and including first-order streams where groundwater discharge is the major hydrologic input. However, similar plant communities may occur in other geomorphic settings not covered in this guidebook, such as depressions in flatwoods and the edges of large floodplains. Headwater Slope wetlands often grade into other wetland subclasses, such as wet flats, tidal fringes, or riverine systems associated with second-order streams or higher. They occur in relatively flat areas, in areas that are gently sloping, and in drainages with pronounced side slopes. Shallow channels may be present in some Headwater Slope wetlands, but where they occur they often are poorly defined and sometimes are braided. Figure 5 illustrates the landscape setting in which Headwater Slope wetlands occur. Headwater Slope wetlands are sometimes difficult to classify because they may have characteristics of more than one HGM class, including flats, slopes, and riverine systems, with which they may intergrade.

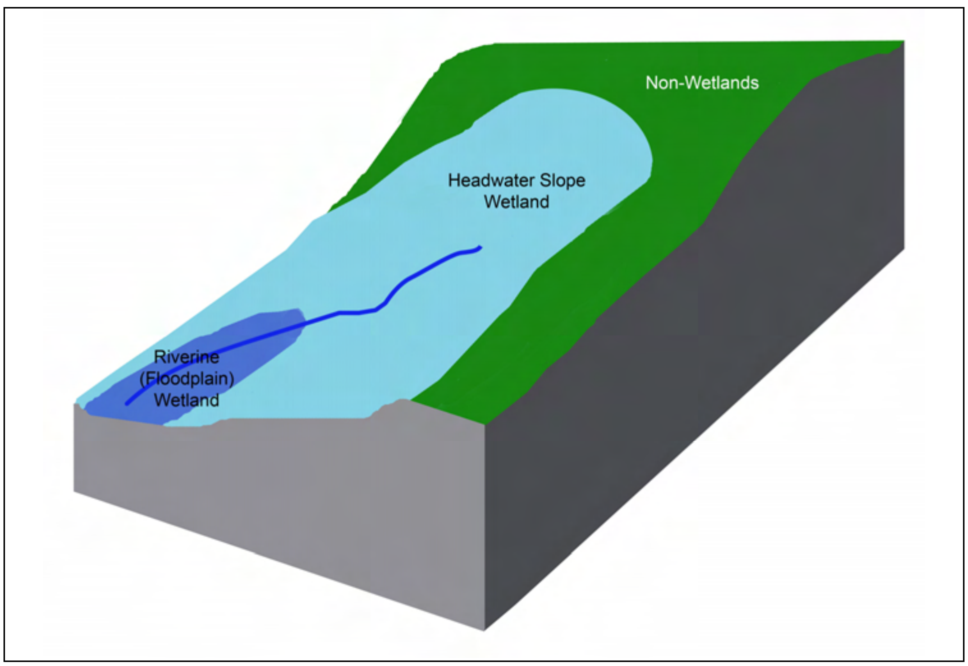

Figure 5. Generalized landscape position of Headwater Slope wetlands in southeast Mississippi and southwest Alabama

Hydrologic regime

One defining characteristic of bayhead wetlands is that their primary source of hydrology is groundwater discharge from adjacent landforms, typically sandy uplands (Nelson 1986; Vince et al. 1989). Even in wetlands in which channels occur, flooding is not the major source of hydrology. Vince et al. (1989) noted that bayheads flooded less often than other types of wetlands, such as hydric hammocks. In most Headwater Slope wetlands, near-surface saturation occurs for at least a portion of the growing season and many remain saturated for most of the year. Simons et al. (1989) noted that "bayhead forests have the most stable supply of moisture of any inland forest type." Headwater Slope wetlands are rarely inundated for extended periods; surface water normally is present only after heavy rains. Ponding occurs in some wetlands, but only in microdepressions. Headwater Slope wetlands within the reference domain do not appear to vary enough hydrologically to warrant classification into more than one subclass.

Soils

Headwater Slope wetlands in the reference domain contain a variety of soils. These include soils with a sand texture greater than 80 in. (2 m) thick to soils with a loamy sand surface and a restrictive sandy clay loam subsurface at approximately 16 in. (40 cm). Some Headwater Slope wetlands have soils with thick organic surfaces that become thinner and may disappear down gradient as the slope wetland grades into a first-order riverine system.

Vegetation

Most authors who have described Headwater Slope wetlands agree that one or more of several species of "bays" including sweetbay (*Magnolia virginiana*), loblolly-bay (*Gordonia lasianthus*), redbay (*Persea borbonia*), and swamp bay (*Persea palustris*) make up a significant proportion of the overstory or midstory (Monk 1966; Nelson 1986; Wharton et al. 1977; U.S. Army Corps of Engineers, Jacksonville District, 1988). Headwater Slope wetland forests have been described by most authors (who referred to them as bayheads) as having dense canopies and tangled midstories and understories of tall shrubs and vines (Wharton et al. 1977; Nelson 1986). Braun (1950) stated that "pine and sweet bay flats with their dense tangle of shrubs and lianas, interrupt the longleaf pine (*Pinus palustris*) woods." Nelson (1986) noted that bayheads sometimes have exposed and highly convoluted roots near the surface. Wharton et al. (1977) described the herbaceous understory as sparse while other authors, including Monk (1966) and Nelson (1986), listed numerous species that occur in the lower strata. U.S. Army Corps of Engineers, Jacksonville District (1988), did not mention herbaceous understory species in their account. A more detailed description of the plant communities within the subclass can be found in the plant community model.

The Society of American Foresters (Eyre 1980) recognizes a "Sweetbay-Swamp Tupelo (*Nyssa sylvatica* var. *biflora*)-Redbay" forest type (Type 104) that is found on moist to wet sites in "branch heads; the narrow bottoms of small perennial or intermittent streams or branches; pocosins; and poorly drained upland depressions in the Coastal Plain" and "the borders of swamps" from

Maryland and southeastern Virginia to southeastern Texas. Species composition is described as highly variable, and associated species include red maple (*Acer rubrum*), blackgum (*Nyssa sylvatica*), loblolly-bay, water oak (*Quercus nigra*), baldcypress (*Taxodium distichum*), slash pine (*Pinus elliottii*), evergreen shrubs, ferns, pitcherplants (*Sarracenia* spp.), and sedges.

Within the reference domain, upland habitats constitute a high percentage of the landscape. The primary forest type of the outer Coastal Plain in much of the reference domain is classified as Longleaf-Slash Pine, with the Oak-Gum-Cypress type dominating the major drainageways (Nelson and Zillgitt 1969; Eyre 1980). Frequent wildfires in the uplands favor longleaf pine and maintain an open understory. With the suppression of fires, slash pine increases in importance and the understory may become dominated by hardwoods and shrubs (Eyre 1980). Besides pines, common species in upland settings include various oaks (*Quercus* spp.), hickories (*Carya* spp.), hawthorns (*Crataegus* spp.), sweetgum (*Liquidambar styraciflua*), yaupon (*Ilex vomitoria*), inkberry (*Ilex glabra*), greenbriers (*Smilax* spp.), wiregrass (*Aristida* spp.), bluestem grasses (*Andropogon* spp.), and forbs.

Relationships to other wetland types

Some Headwater Slope wetlands outside the reference domain but in the Coastal Plain are not dominated by bays and are referred to by other names. For example, white cedar (*Chamaecyparis thyoides*) swamps (Wharton et al. 1977; Laderman 1989), hydric hammocks (Vince et al. 1989), titi (*Cyrilla racemiflora*) swamps (U.S. Army Corps of Engineers, Jacksonville District, 1988), and Carolina bays (Laderman 1989) are composed of similar species and are found in generally similar landscape positions. Wharton et al. (1977) indicated that the bayhead community may occur in a landscape mosaic of white cedar swamps, pond pine (*Pinus serotina*) woodland, and pocosins. They further noted that a number of communities may grade into bay forests.

Because bayheads and wetlands dominated by other plant communities commonly occur in similar landscape positions (e.g., depressions and drainages in headwater areas) and have similar groundwater-dominated hydrology, it is likely that they simply represent a continuum of community types with disturbance, particularly fire, playing a decisive role in determining point-in-time plant species composition. Wharton et al. (1977) stated that "bay forests are thought to succeed from Atlantic white cedar swamps in the absence of fire." U.S. Army Corps of Engineers, Jacksonville District (1988), noted similar relationships between white cedar and bay swamps in Florida. Interestingly, fire intensity may be one of the factors that influence the interactions between these two types of headwater wetlands. Wharton et al. (1977) stated that severe fires may result in bay forests reverting to Atlantic white cedar. The role that fire plays in the dynamics of these communities is complex. Laderman (1989) noted that stands of white cedar may be destroyed by intense fire, but "light" fire reduces competition and permits cedar reproduction. Monk (1966, 1968) believed that bayheads are climax communities and may be "preceded (in succession) by pond pine or cypress wetlands." Fires occur in bayheads periodically, and bays have apparently evolved adaptations to it. For example, Clewell (1971) noted that bays have the ability to sprout from top-killed stumps.

Anthropogenic alterations

Although it is difficult to determine the conditions that existed within the reference domain prior to its current altered state, descriptions by explorers and early settlers indicate that the majority of the region consisted of open woods and savannas maintained by frequent fires (Ware et al. 1993; Rheinhardt et al. 2002). Most fires were caused by lightning although some were set by native people to improve habitat for game. Fires burned extensively across both upland forests and wet flats during dry periods, although the frequency of fire in headwater wetlands and stream drainages may have been reduced by the presence of saturated soils for much of the year (Rheinhardt et al. 2002).

Since European settlement, Headwater Slope wetlands have been impacted by forest clearing and subsequent filling or draining for agricultural production. Land clearing and timber harvest have also occurred in the adjacent upland landscape resulting in the creation of wetland islands and corridors surrounded mostly by agricultural land.

Worldwide, conversion for agriculture continues to be the major cause of wetland destruction (Mitsch and Gosselink 2000). However, within the reference domain, most of the recent impacts to wetlands have been for residential or industrial development and road or bridge construction. Regardless of the mechanisms, the amount of development in the reference domain has been extensive, resulting not only in the loss of Headwater Slope wetlands, but also in the loss of other habitats closely associated with them.

4 Wetland Variables, Functions, and Assessment Models

Variables

The following variables are used to assess the functions that are performed by Headwater Slope wetlands in southern Alabama and Mississippi:

a. Canopy Tree Diameter

b. Canopy Tree Density

c. Ground Vegetation Cover

d. Habitat Connections

e. Hydrologic Alterations

f. Sapling/Shrub Cover

g. Soil Detritus

h. Surface Soil Organic Matter Content

i. Upland Land Use

j. Vegetation Composition and Diversity

k. Change in Catchment Size

Each variable is defined and the rationale for its selection is discussed in the following paragraphs. The relationship of each variable to functional capacity is also given, based on measurements taken in reference wetlands in the Alabama and Mississippi coastal plains. Procedures for measuring each variable in the field can be found in Chapter 5.

Canopy tree diameter (V_{CTD})

This variable is the average diameter at breast height (dbh) of canopy trees measured at 1.4 m (55 in.) above the ground. This variable is measured only if percentage tree cover is 20 percent or greater. Canopy trees are defined as self-supporting woody plants ≥10 cm (4 in.) dbh, whose crowns compose the uppermost stratum of the vegetation. Canopy trees are not immediately overtopped by

taller trees and would be clearly seen by an airborne observer (Figure 6). Tree diameter is a common measure of dominance in forest ecology, used either alone or in combination with tree density and basal area (Whittaker et al. 1974; Whittaker 1975; Spurr and Barnes 1981; Tritton and Hornbeck 1982; Bonham 1989). It expresses the relative age or maturity of a forest stand. V_{CTD} applies to all functions.

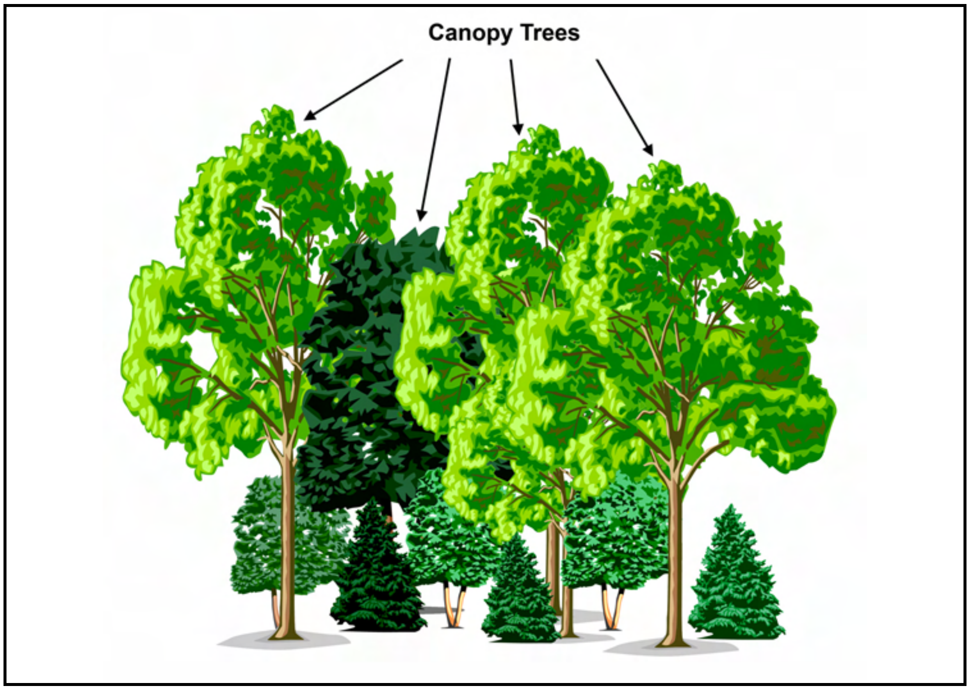

Figure 6. Example of canopy trees. Although not necessarily the tallest trees in a stand, canopy trees have no other tree foliage directly above them

In Headwater Slope reference wetlands, the average dbh of canopy trees ranged from 0.0 cm on sites where all trees had been removed to 44 cm (17 in.) in mature forest stands. Based on data from reference standard sites, a variable subindex of 1.0 is assigned when mean dbh is ≥30 cm (12 in.). A subindex value of 0.1 is assigned to severely altered sites where there is <20 percent canopy cover of trees and the tree stratum is not sampled. Therefore, mean dbh would be <10 cm. The relationship between canopy tree diameter and functional capacity of a Headwater Slope wetland is assumed to be linear; thus the subindex increases linearly from 0.1 to reference standard values (Figure 7).

Canopy tree density (V_{CTDEN})

This variable is defined as the density of canopy trees expressed as the number of tree stems per hectare. Canopy trees are defined as woody plants ≥10 cm (4 in.) dbh whose crowns compose the uppermost stratum of the vegetation (see V_{CTD}). This variable is measured only if percentage tree cover is 20 percent or greater. Tree density, in combination with average tree diameter, is a measure of the dominance and biomass of trees in a forest stand. V_{CTDEN} applies to all functions.

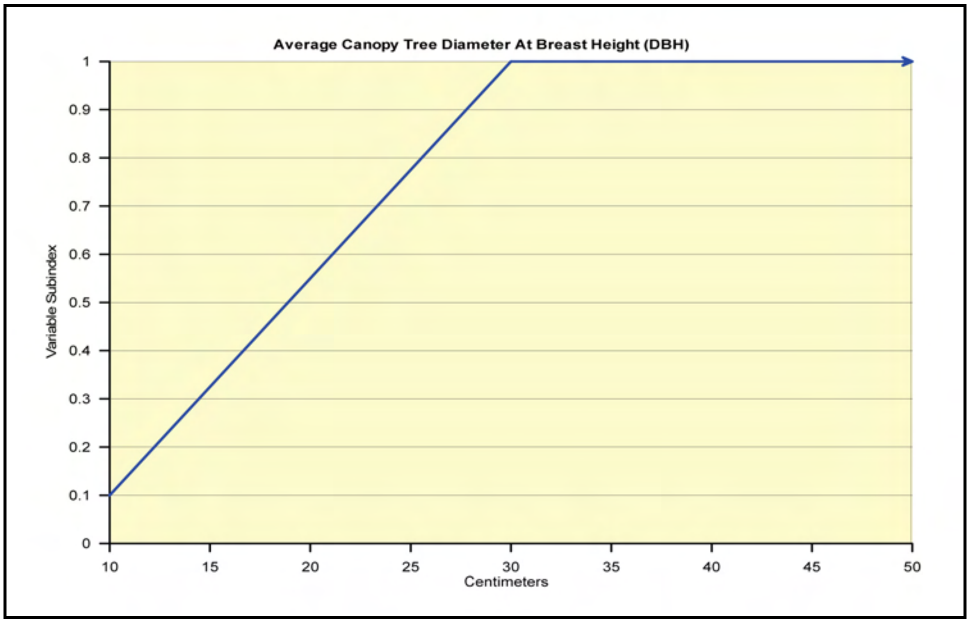

Figure 7. Relationship between average canopy tree diameter (V_{CTD}) at breast height and functional capacity

In Headwater Slope reference wetlands, the average canopy tree density ranged from 0.0 stems/ha on sites where all trees had been removed to 975 stems/ha in the densest stands. Based on data from reference standard sites, a subindex value of 1.0 is assigned when the density of canopy trees is between 250 and 425 stems/ha. A subindex value of 0.0 is assigned to severely altered sites that lack canopy trees and have density values of zero. At sites on which canopy tree density is between zero and the minimum reference standard value, the relationship between canopy tree density and the capacity to support characteristic wetland processes is assumed to be linear. During mid-successional stages, canopy tree density may exceed that in reference standard sites, and it is assumed that characteristic processes will be adversely affected (Figure 8).

Ground vegetation cover (V_{GVC})

This variable is defined as the average percentage cover of ground vegetation inside a 0.04-ha plot. Ground vegetation is defined as all herbaceous vegetation, regardless of height, and woody vegetation <1 m (39 in.) in height. Ground vegetation cover is an index to the abundance and biomass of low vegetation in Headwater Slope wetlands, which affect the productivity and structure of these habitats. V_{GVC} applies only to the biogeochemistry, plant community, and wildlife habitat functions and only when canopy tree cover and shrub cover are each less than 20 percent.

On reference standard sites, coverage of ground-layer vegetation ranged from 78 to 91 percent. However, V_{GVC} is not used to evaluate Headwater Slope wetlands that have a well-developed tree or sapling/shrub canopy. Instead, V_{GVC} is measured only in areas where tree and sapling/shrub cover are both <20 percent due to severe natural or anthropogenic disturbance. Even under these conditions, ground-layer vegetation contributes some organic material to the wetland's

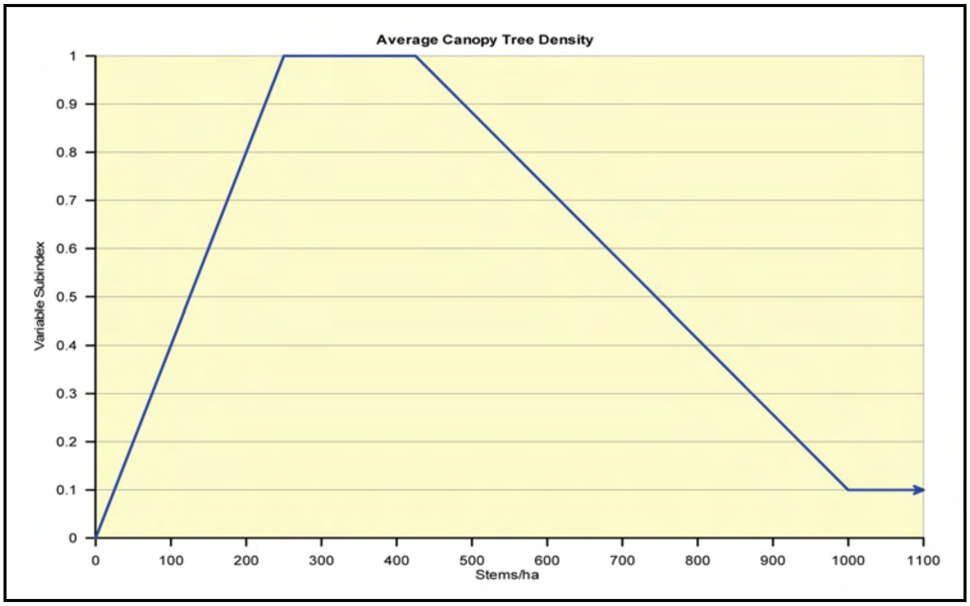

Figure 8. Relationship between average canopy tree density (V_{CTDEN}) and functional capacity

carbon cycle, provides some benefits for wildlife, and helps produce conditions favorable to the regeneration of a woody midstory and canopy. Ground vegetation cover on reference sites with <20 percent tree and sapling/shrub cover ranged from 20 to 84 percent. A subindex of 1.0 is assigned when ground vegetation cover is ≥70 percent (Figure 9).

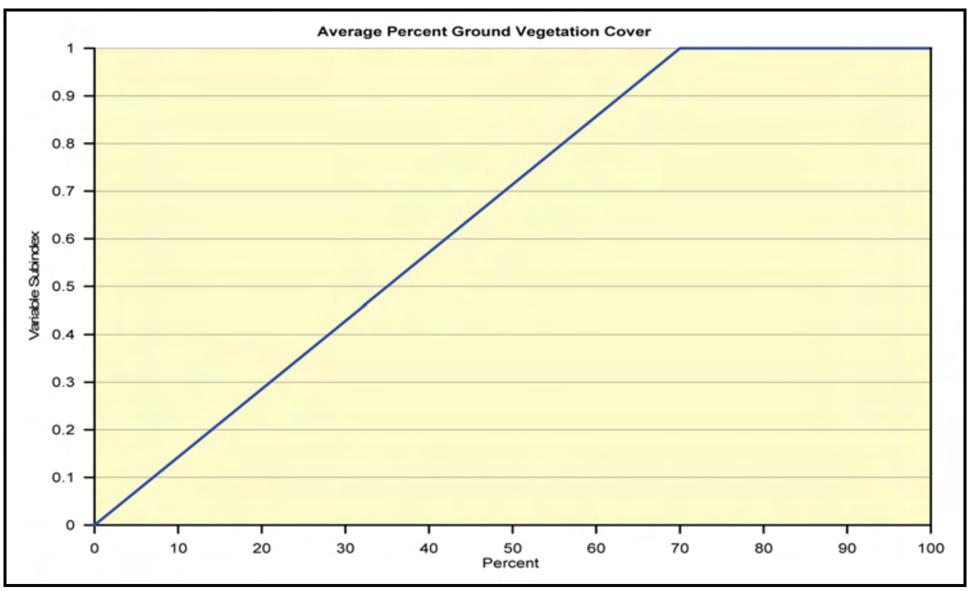

Figure 9. Relationship between average percentage ground vegetation cover (V_{GVC}) and functional capacity

Habitat connections ($V_{CONNECT}$)

This variable is defined as the percentage of the wetland perimeter and width of suitable wetland or upland wildlife habitat that is connected to the wetland. To be considered in this calculation, a zone or buffer of suitable habitat must extend at least 10 m (32.8 ft) beyond the wetland boundary. It is assumed here that nearly all forested areas with normal stocking will provide at least minimally suitable habitat for amphibians and most other small wildlife species that may depend on wetlands and adjacent habitats for food, cover, and breeding sites. Other suitable community types include prairie, savanna, and scrub/shrub habitats. Managed pine forests and plantations are considered suitable only if soils, litter, and ground-layer vegetation have not been disturbed extensively (e.g., bedded) such that cover has been eliminated and animal movement is impeded. Areas devoted to row crops, closely mowed areas, grazed pastures, and urban areas are not suitable habitat. $V_{CONNECT}$ applies only to the wildlife habitat function.

The width of the habitat that is connected to the wetland also is considered in this variable. Ideally a zone or buffer of suitable habitat should extend 150 m (492 ft) or more beyond the wetland boundary, and that condition existed at all reference standard wetlands sampled. A narrower zone or buffer can, however, provide habitat for many amphibian, reptile, and avian species that utilize Headwater Slope wetlands; thus the Connection Index from Figure 10 must be modified to determine the final subindex. This is done by multiplying the above value by one of the following constants. If the width is $\geq$ 10 m and < 30 m (32.8 to 98.4 ft), multiply by 0.33; if the width is $\geq$ 30 m and < 150 m (98.4 to 492 ft), multiply by 0.66; if the width is $\geq$ 150 m (492 ft), multiply by 1.0. The resulting number is the subindex for $V_{CONNECT}$.

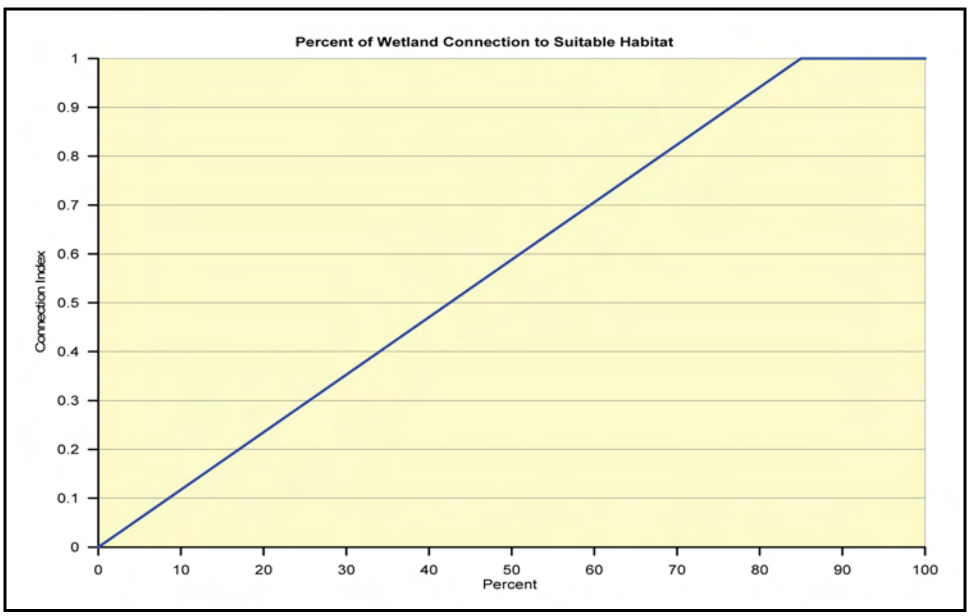

Figure 10. Relationship between the percentage of the wetland perimeter that is connected to suitable wildlife habitat ($V_{CONNECT}$).

A subindex value of 0.0 is assigned to sites where none of the wetland perimeter is buffered by a zone of suitable habitat. Reference standard wetlands have 85 to 100 percent of their perimeters suitably buffered by a zone at least 150 m (492 ft) wide. At sites where the percentage of the wetland perimeter with a suitable buffer is between 0 and 85 percent, or the width is less than 10 m (32.8 ft), the relationship between the amount of suitable buffer and functional capacity is reduced.

Hydrologic alterations ($V_{HYDROALT}$)

This variable reflects alterations to the natural hydrology of the Headwater Slope wetland caused by activities within the wetland boundary. Both natural and man-induced alterations can affect the hydrology of a Headwater Slope wetland. Examples in the reference domain include ditches, dams, culverted and unculverted road crossings, excavation of the wetland, and headcutting of streams. The intent of this variable is to capture those impacts that alter the period of saturation or water storage capacity of the Headwater Slope wetland. This variable differs from V_{CATCH} and V_{UPUSE} (to be described later) in that the impacts occur within the wetland and not in the surrounding landscape. $V_{HYDROALT}$ applies only to the hydrology, biogeochemistry, and wildlife habitat functions.

The hydrology of unaltered Headwater Slope wetlands is dominated by groundwater, although in some reference standard sites shallow surface water may be present for short periods in early spring or after storm events. Under reference standard conditions (subindex = 1.0), there were no alterations to the natural hydrology of Headwater Slope wetlands. While surface water greater than 2.5 cm (1 in.) was not observed at any reference standard sites, there was evidence (drift lines, water marks) that surface water was as high as 8 cm (3 in.) for short periods. Based on this evidence, it is assumed that surface water 8 cm (3 in.) or less would receive a subindex score of 1.0. Impacts to the natural hydrologic regime are assumed to be proportional to the depth of surface water greater than 8 cm (3 in.) that could be retained in the wetland due to a dam or other structure (Figure 11), or to the depth of a drainage ditch or other excavation within the wetland. Impacts that alter the storage capacity by 60 cm (24 in.) can alter the wetland to the extent that the hydrogeomorphic classification of the Headwater Slope wetland would change to a depressional or lacustrine fringe wetland, or the wetland could be drained to the extent that it would no longer have wetland hydrology. Impacts of this magnitude were assigned a subindex value of 0.0 (Figure 12). Some impacted sites in the reference domain had impounded water greater than 1 m (39 in.) deep.

Sapling/shrub cover (V_{SSC})

This variable is defined as the average percent cover of woody vegetation >1 m (39 in.) in height and <10 cm (4 in.) dbh (e.g., shrubs, saplings, and understory trees). Shrubs contribute to the structure of the wetland plant community, particularly if trees are absent. They take up nutrients, produce biomass, and provide cover and breeding sites for wildlife. Shrubs may dominate the community in Headwater Slope wetlands during early to midsuccessional stages. V_{SSC} applies only to the biogeochemistry, plant community, and wildlife habitat functions and is measured only if tree canopy cover is <20 percent.

Figure 11. Water marks on trees are evidence of ponding, in this case caused by blocking of water flow by a road

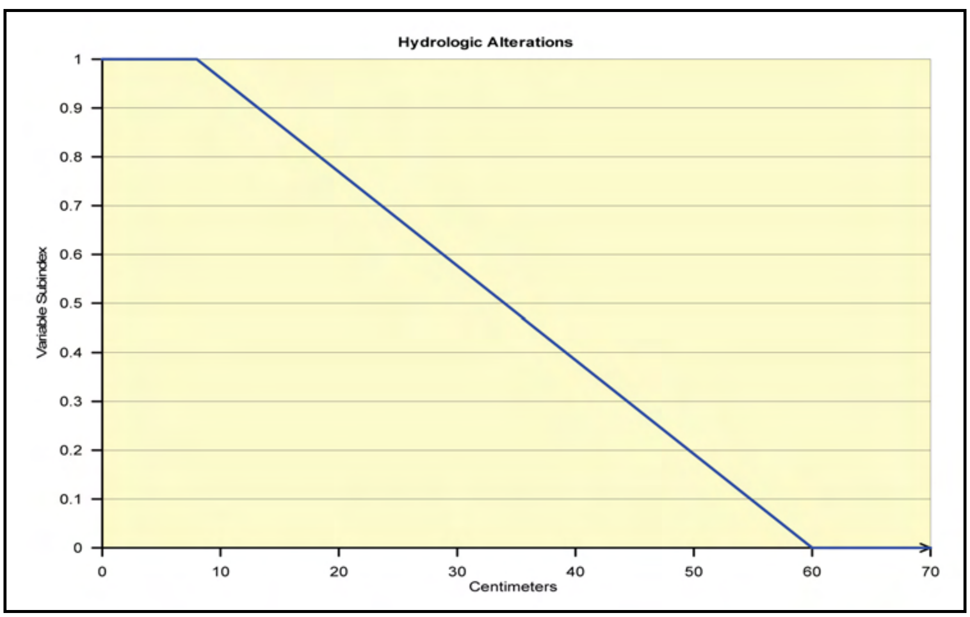

Figure 12. Relationship between depth or height of drainage or impoundment ($V_{HYDROALT}$) and functional capacity

Sapling/shrub cover was highly variable in reference standard wetlands, ranging from 4 to 91 percent. However, V_{SSD} is not used to evaluate Headwater Slope wetlands that have a well-developed tree canopy. Instead, V_{SSD} is measured only in areas with <20 percent tree cover caused by recent natural or anthropogenic disturbance. In this context, V_{SSD} reflects the amount of woody regeneration on the site that contributes immediately to carbon cycling and provides habitat for wildlife, and will eventually reproduce a mature forest canopy. Therefore, higher values of sapling/shrub cover are assumed to contribute more to these functions. Sapling/shrub cover on reference wetland sites with <20 percent tree cover ranged from 0 to 90 percent. Based on reference data, a subindex of 1.0 is assigned when sapling/shrub cover is $\geq$70 percent (Figure 13).

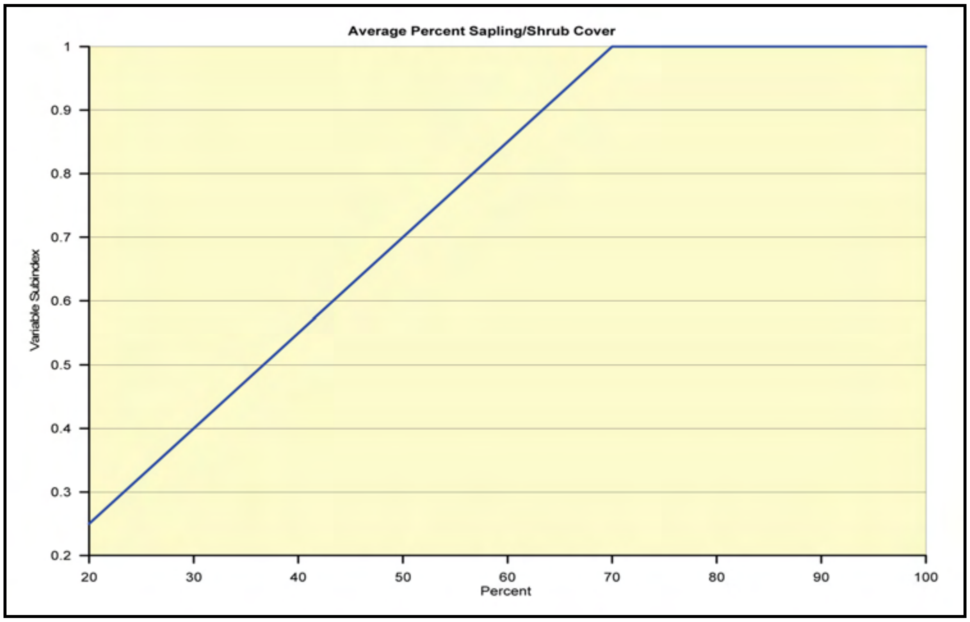

Figure 13. Relationship between average percentage cover of saplings and shrubs (V_{SSC}) and functional capacity

Soil detritus ($V_{DETRITUS}$)

This variable consists of the percentage cover of detrital material on the soil surface. Soil detrital material is defined as the soil layer dominated by partially decomposed but still recognizable organic material, such as leaves, sticks, needles, flowers, fruits, insect frass, dead moss, or detached lichens on the surface of the ground. This material would classify as fibric or hemic material (peat or mucky peat). Detritus is a direct indication of short-term (1 or 2 years) accumulation of organic matter primarily from vegetation within the wetland. $V_{DETRITUS}$ applies only to the biogeochemistry function.

The cover of soil detritus in Headwater Slope reference wetlands ranged from 0 to 100 percent. Based on data from reference standard wetland sites, a variable subindex of 1.0 is assigned when detrital cover is between 97 and 100 percent (Figure 14). The main reasons that detrital cover is reduced or lacking entirely are reduced tree cover and increased water flow across the

Figure 14. View of Headwater Slope wetland showing 100 percent cover of soil detritus

headwater wetland. Increased water flow washes the detrital cover downstream. Sites lacking detrital cover are assigned a subindex of 0.0. A linear increase in the subindex score as detrital cover increases from 0 to 97 percent is assumed (Figure 15).

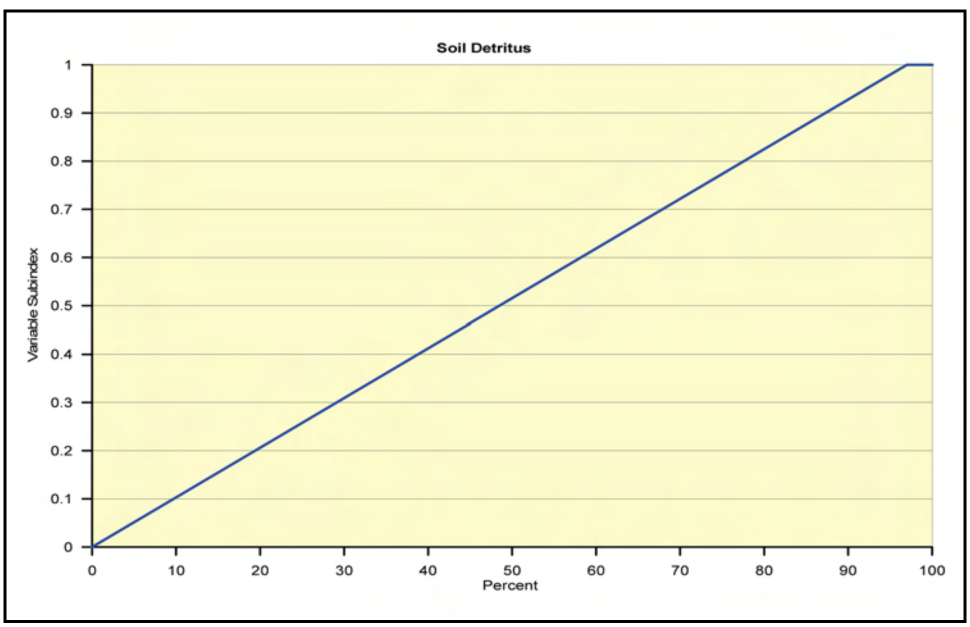

Figure 15. Relationship between average percentage cover of detritus ($V_{DETRITUS}$) and functional capacity

Surface soil organic matter content (V_{SSOM})

Surface soil organic matter is defined as the amount of organic matter present in the surface soil layer or horizon, immediately below the detrital layer, if present. Soil organic matter is the result of long-term (at least several years) accumulation from the decomposition of the detrital layer by microorganisms and incorporation into the soil. Direct measurement of the percentage of organic matter in the soil is not practical for a rapid assessment. A relative determination of the soil organic matter content can be made using soil color "value," part of the Munsell system of color notation. Darker (i.e., lower value) colors indicate higher amounts of soil organic carbon. V_{SSOM} applies only to the biogeochemistry function.

In Headwater Slope reference wetlands in Mississippi and Alabama, Munsell soil color values ranged from 2 to 7. Based on data from reference standard sites, a variable subindex of 1.0 is assigned to wetland sites with average soil color values of 2.5 or less (see Appendix B). Average Munsell soil color values greater than 6.5 in the surface layer indicate a very low percentage of organic matter and severely altered conditions. These sites are assigned a subindex of 0.0. The rate at which the subindex decreases is based on the assumption that the relationship between color value and biogeochemical processes in Headwater Slope wetlands is linear (Table 5).

Table 5
Relationship Between Surface Soil Color Value and Functional Capacity

Munsell Soil Color Value	Subindex Score
Less than or equal to 2.5	1.0
Greater than 2.5, but less than or equal to 3.5	0.8
Greater than 3.5, but less than or equal to 4.5	0.6
Greater than 4.5, but less than or equal to 5.5	0.4
Greater than 5.5, but less than or equal to 6.5	0.2
Greater than 6.5, but less than or equal to 10	0.0

Upland land use (V_{UPUSE})

This variable is defined as the surface water runoff potential from the wetland catchment into the wetland. With increased disturbance and increased impervious surface surrounding the wetland, more surface water enters the wetland than under reference standard conditions. Burned natural areas should not receive an increased score. Runoff scores are based on runoff curves developed by the NRCS. Runoff curve numbers are a function of land use and soil type. For this Headwater Slope guidebook, curve numbers are estimated based on land use and hydrologic soil groups A through D (Table 6). Hydrologic soil groups are based on soil properties such as texture and depth to restrictive layers. Aerial photographs depicting land use are available from a number of Internet sources including TerraServer (http://terraserver.homeadvisor.msn.com/), Google Maps (http://maps.google.com/), and Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/). The latter site also provides the most current soil survey maps.

Table 6 Runoff Curve Numbers				
	Hydrologic Soil Groups			
Upland Land Use	**A**	**B**	**C**	**D**
Open space (pasture, lawns, parks, golf courses, cemeteries):				
Poor condition (grass cover <50%)	68	79	86	89
Fair condition (grass cover 50% to 75%)	49	69	79	84
Good condition (grass cover >75%)	39	61	74	80
Impervious areas (parking lots, roofs, driveways, etc)	98	98	98	98
Gravel	76	85	89	91
Urban districts:				
Commercial and business (85% cover)	89	92	94	95
Industrial (72% cover)	81	88	91	93
Residential districts by average lot size:				
1/8 acre or less (town houses and apartments) (65% cover)	77	85	90	92
1/4 acre (38% cover)	61	75	83	87
1/3 acre (30% cover)	57	72	81	86
1/2 acre (25% cover)	54	70	80	85
1 acre (20% cover)	51	68	79	84
2 acres (12% cover)	46	65	77	82
Newly graded areas (no vegetation or pavement)	77	85	90	92
Fallow crop areas (poor)	76	85	90	93
Fallow crop areas (good)	74	83	88	90
Row crops	70	80	86	90
Small grain	64	75	83	87
Groves and orchards (<50% ground cover)	57	73	82	86
Groves and orchards (50% to 75% ground cover)	43	65	76	82
Groves and orchards (>75% cover)	32	58	72	79
Forest and native range (<50% ground cover)	45	66	77	83
Forest and native range (50% to 75% ground cover)	36	60	73	79
Forest and native range (>75% ground cover)	30	55	70	77
Modified from USDA Natural Resources Conservation Service (1986).				

Hydrologic soil groups for soil series found within the reference domain can be found in Table B1 (Appendix B), local soil surveys, or at the Soil Data Mart (http://soildatamart. nrcs.usda.gov/). The subindex score for V_{UPUSE} is based on the weighted average of runoff scores for land uses and soils identified in the upland catchment of the Headwater Slope wetland (see Appendix B for an example calculation). V_{UPUSE} applies only to the hydrology function.

Headwater Slope reference standard wetlands were surrounded in their catchments by native vegetative communities. Under reference standard conditions, native upland plant communities have runoff scores of 55 or less and would receive a subindex of 1.0 (Figure 16). Land uses that significantly increase the amount of runoff into a Headwater Slope wetland are assumed to be detrimental to the characteristic hydrologic regime of the wetland. The subindex for this variable is assumed to decline linearly to zero as the weighted average runoff score increases from 55 to 98.

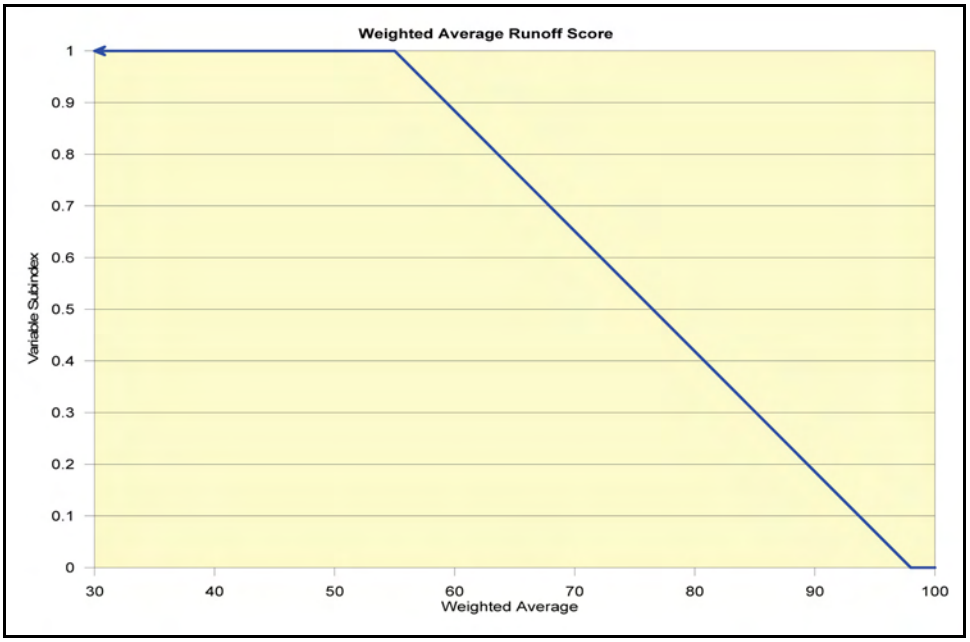

Figure 16. Relationship between weighted average runoff score of uplands in the catchment of the Headwater Slope wetland (V_{UPUSE}) and functional capacity

Vegetation composition and diversity (V_{COMP})

This variable reflects the "floristic quality" of the community based on concepts in Andreas and Lichvar (1995) and Smith and Klimas (2002). The focus is on the plants that dominate the tallest stratum present, as recommended by Smith and Klimas (2002). In reference standard Headwater Slope wetlands, the tallest stratum is composed of native canopy trees. In wetlands that have undergone recent and severe natural or anthropogenic disturbance, the tallest stratum may be dominated by herbaceous species or shrubs. Implicit in this approach is the assumption that the "quality" of the tallest layer is a good indicator of overall community composition and successional patterns (i.e., appropriate shrub composition indicates appropriate future canopy composition). Most reference standard wetlands within the reference domain are relatively diverse with several dominant species present. Dominant species are determined using the 50/20 rule described in Figure 17. Note that the tree stratum includes all trees $\geq$10 cm (4 in.) dbh and not just canopy trees.

Dominant species are classified into three groups reflecting presumed floristic quality (Table 7). Group 1 consists of species that characterize undisturbed Headwater Slope wetlands in Alabama and Mississippi. These include the various species of "bays" as well as swamp tupelo and slash pine. Group 2 consists of other native plant species that are often present in Headwater Slope wetlands that have been disturbed or altered. Group 3 consists of non-native (exotic) species or native invasive species that usually are found on highly degraded sites.

Steps in the 50/20 Rule for Selecting Dominant Plant Species:

1. Apply this procedure only to the tallest stratum present. To count as present, the total cover of the tree and sapling/shrub strata must be ≥20 percent.
2. Estimate the absolute percentage cover of each species in the tallest stratum.
3. Rank all species in the stratum from most to least abundant.
4. Calculate the total coverage for all species in the stratum (i.e., sum their individual percentage cover estimates). Absolute cover estimates do not necessarily sum to 100 percent.
5. Select plant species from the ranked list, in decreasing order of coverage, until the cumulative coverage of selected species exceeds 50 percent of the total coverage for the stratum. The selected species are all considered to be dominants. All dominants must be identified to species.
6. In addition, select any other species that, by itself, is at least 20 percent of the total percentage cover in the stratum. Any such species is also considered to be a dominant and must be identified accurately.

Figure 17. Description of the 50/20 rule

Table 7
Quality Scores for Dominant Plant Species Used to Calculate V_{COMP}

Scientific Name[1]	Common Name	Score
	Group 1	
Magnolia grandiflora	Southern Magnolia	1.0
Magnolia virginiana	Sweetbay	
Nyssa biflora	Swamp Tupelo	
Persea borbonia	Redbay	
Persea palustris	Swamp Bay	
Pinus elliottii	Slash Pine	
	Group 2[2]	
Acer rubrum	Red Maple	0.66
Liquidambar styraciflua	Sweetgum	
Liriodendron tulipifera	Tuliptree	
Nyssa sylvatica	Blackgum	
Quercus laurifolia	Laurel Oak	
Quercus nigra	Water Oak	
	Group 3[3]	
Albizia julibrissin	Silktree	0.0
Alternanthera philoxeroides	Alligatorweed	
Aster tataricus	Tatarian Aster	
Briza minor	Little Quakinggrass	
Cerastium fontanum	Common Mouse-Ear Chickweed	
Imperata cylindrica	Cogon grass	
Ligustrum japonicum	Japanese privet	
Ligustrum sinense	Chinese Privet	
Lonicera japonica	Japanese Honeysuckle	
Lygodium japonicum	Japanese Climbing Fern	
Microstegium vimineum	Nepalese Browntop	
Panicum repens	Torpedo grass	
Pueraria montana	Kudzu	
Sorghum halepense	Johnsongrass	
Triadica sebifera	Chinese tallow	
Verbena brasiliensis	Brazilian Vervain	

[1] Plant names according to the USDA Plants database (http://plants.usda.gov/).
[2] Other native plant species may be added to Group 2.
[3] Other non-native or invasive plant species may be added to Group 3.

In reference standard Headwater Slope wetlands within the reference domain, dominant vegetation composition included species from Groups 1 and 2, and the number of dominants was 4 or greater. As either composition or richness deviates from those conditions, functional capacity is assumed to decline. The procedure used to calculate a subindex value for V_{COMP} is described in Chapter 5 and incorporates both richness and quality of dominant species (Peterson et al. 2005). V_{COMP} applies only to the plant community function.

Change in catchment size (V_{CATCH})

This variable is defined as the change in the size of the wetland catchment, watershed, or basin as a result of human activities in the landscape of the wetland. The intent of this variable is to assess the change in the amount of water delivered to the wetland from alterations to the watershed that either reduce or augment surface or subsurface flows. V_{CATCH} applies only to the hydrology function.

In the case of water diversions away from the Headwater Slope wetland by ditches, berms, or other features in the catchment, the change is quantified as a percentage loss of catchment area by using the following formula (Equation 1):

$$Percent\ change = \left[\left(\frac{Natural\ catchment\ size\ -\ Existing\ catchment\ size}{Natural\ catchment\ size}\right)\times 100\right] \qquad (1)$$

In the case of water transfers into the wetland catchment from another basin, the change is calculated as a percentage increase in effective catchment area as follows (Equation 2):

$$Percent\ change = \left[\left(\frac{Area\ of\ catchment\ from\ which\ water\ is\ being\ transferred}{Wetland\ natural\ catchment\ size}\right)\times 100\right] \qquad (2)$$

If the effective size of the catchment is unchanged (i.e., no water diversions), then the subindex score is 1.0. In Headwater Slope wetland reference sites, percentage change in the size of the wetland catchment ranged from 0 to 73 percent. The size of the catchment of reference standard wetland sites had no change (i.e., percent change = 0). The relationship between functional capacity and the percent change in catchment area is assumed to decline linearly to 0.1 when the percentage change equals 100 percent (Figure 18). This is based on the assumption that, as the effective size of the catchment decreases, the amount of water entering the wetland is proportionately reduced and is not available for storage in the wetland. However, the subindex does not go to zero because the wetland still receives direct precipitation and could still receive some subsurface input from the surrounding area. Additions of water to the wetland catchment are assumed to impact the natural hydrology of the wetland to the same extent as diversions. In the case of water transfers into the wetland catchment, the percentage change in effective catchment area can exceed 100 percent.

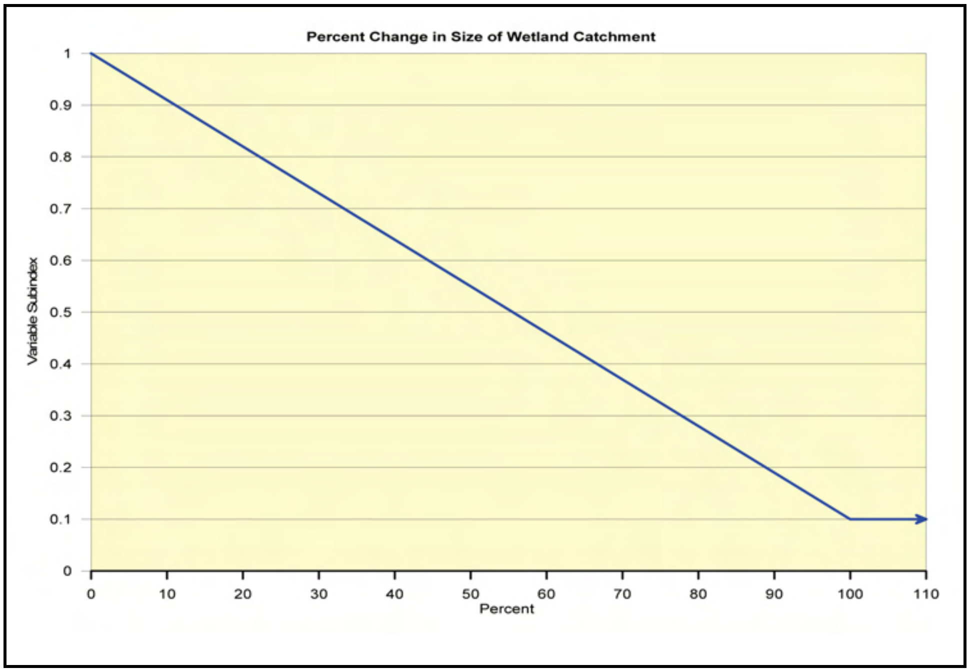

Figure 18. Relationship between the percentage change in effective size of the wetland catchment (V_{CATCH}) and functional capacity

Functions

The following sequence is used to present and discuss each function:

a. *Definition:* Defines the function.

b. *Rationale for selecting the function*: Provides the rationale for why a function was selected and discusses onsite and offsite effects that may occur as a result of lost functional capacity.

c. *Characteristics and processes that influence the function*: Describes the characteristics and processes of the wetland and the surrounding landscape that influence the function and lay the groundwork for the description of model variables.

d. *Functional capacity index*: Describes the assessment model from which the functional capacity index is derived and discusses how model variables interact to influence functional capacity.

Function 1: Water Storage

Definition

The function Water Storage is defined as the capacity of the Headwater Slope wetland to store water within the soil for a few days to a few weeks and slowly release this water to downslope wetlands or streams. A potential independent, quantitative measure for validating the functional index is a direct

measurement of the amount of water that is dynamically stored within the wetland over a portion of the year.

Rationale for selecting the function

The annual water budget of Headwater Slope wetlands is controlled mainly by interception of the groundwater table and secondarily by precipitation and upland runoff. Performance of the function Water Storage causes the wetland to retain subsurface water inputs for a sufficient period of time to develop other wetland characteristics (e.g., hydric soils, hydrophytic vegetation). Storage also alters the amount and timing of runoff from a catchment into streams, reducing the pulse of runoff that occurs following a storm event and prolonging the period of discharge into streams. In southern Mississippi and Alabama, the principal source of water for short-term storage in headwater wetlands is discharge of groundwater from the surrounding uplands. Loss of water that has been dynamically stored occurs mainly through evapotranspiration, runoff, or subsurface flow. The rate of groundwater movement is controlled by the hydraulic conductivity of the soil.

Water Storage has a significant effect on elemental cycling in the wetland. Prolonged saturation leads to anaerobic soil conditions and initiates chemical reactions that are highly dependent upon the redox capacity of the soil (Mausbach and Richardson 1994). The oxygen concentration in wetland soils greatly affects the redox potential and the chemical cycling properties of elements and compounds, particularly nutrients. This function also has important impacts on invertebrate and vertebrate populations. For example, some invertebrates, such as midges, have very rapid life cycles and are highly adapted to ephemeral wetlands.

Characteristics and processes that influence the function

The characteristics and processes that influence the capacity of a headwater wetland to store water have both natural and anthropogenic origins. Climate, landscape-scale geomorphic characteristics, and characteristics of the soil within and around the wetland are factors largely established by natural processes. Anthropogenic alterations of a wetland (e.g., tilling, cattle grazing, logging) also influence the way a wetland stores surface water (Figure 19). Such effects may take the form of the dominant land use in and near the wetland and may depend on whether the wetland has been hydrologically modified through ditching or damming.

In southern Mississippi and Alabama, rain is fairly evenly distributed throughout the year. Summer thunderstorms are common and tropical storms and hurricanes occasionally affect the area. Surface soil saturation can occur during any month and in some wetlands is evident all year. In others, saturation to the surface is most evident in late winter and early spring before trees have completely leafed out.

Figure 19. Logging of Headwater Slope wetlands not only alters the vegetative community, but drastically changes the hydrologic regime, natural biogeochemical processes, and wildlife habitat

Soil properties of Headwater Slope wetlands are highly variable. Some soils in the reference domain are very sandy and have high hydraulic conductivities. In contrast, some headwater wetlands contain clay loam or organic-textured soils that restrict hydraulic conductivity, slowing the release of stored water. Therefore, the duration of water storage in headwater wetlands in the reference domain can be extremely variable.

In addition to geomorphic and climatic processes, human activities may also have a profound effect on the storage of water within a slope wetland. Modifications to the uplands surrounding the wetland or directly to the wetland itself may affect the receipt and retention of water. Land-use changes such as soil compaction, cultivation, road construction, urban development, and changes in evapotranspiration that result from grazing or logging are modifications that directly affect this function. Many headwater wetlands and/or the lands surrounding them are either grazed or cultivated, depending on dominant landform and characteristics that favor one land use type over another.

Ditching or tiling for the purpose of draining a wetland (e.g., to put it into crop or timber production) and damming a wetland to provide stormwater retention have modified many headwater wetlands. Such modifications so significantly affect the natural short-term water storage of the headwater wetland that many such wetlands lose their natural wetland characteristics and may change HGM wetland subclass or class, or no longer meet the definition of a wetland at all.

Functional Capacity Index

The following variables are used in the assessment model for the function Water Storage:

- Hydrologic Alterations ($V_{HYDROALT}$)
- Change in Catchment Size (V_{CATCH})
- Upland Land Use (V_{UPUSE})
- Canopy Tree Diameter (V_{CTD})
- Canopy Tree Density (V_{CTDEN})

The assessment model for calculating the FCI for Water Storage is as follows (Equation 3):

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{CATCH} + V_{UPUSE}}{2} \right) + \left(\frac{V_{CTD} + V_{CTDEN}}{2} \right)}{2} \right] \right\}^{1/2} \tag{3}$$

In this model (Equation 3), the water storage capacity of Headwater Slope wetlands depends on inputs of water from groundwater and runoff from the surrounding upland. Water is removed from the system in surface and subsurface outflow and evapotranspiration. The model assumes that if (a) natural hydrologic inputs from groundwater and runoff from the surrounding uplands are unaltered, (b) outflow is not increased by drainage ditches or headcutting or blocked by anthropogenic obstructions such as dams, and (c) a mature forest is present to remove water through evapotranspiration at characteristic rates, then the wetland is functioning at reference standard condition.

This model addresses three main factors that influence wetland water storage. The first part of the equation reflects natural or anthropogenic alterations to the wetland ($V_{HYDROALT}$) that affect its capacity to store groundwater for short periods. However, storage of atypically large amounts of surface water due to damming the wetland results in a decrease in FCI. The second part of the equation is a combination of factors affecting the supply of water from the surrounding uplands (V_{CATCH} and V_{UPUSE}) through runoff and shallow groundwater flow, and the effect of a mature tree canopy (V_{CTD} and V_{CTDEN}) on removal of water through evapotranspiration. Each pair of variables in the second part of the equation is averaged and then the two parts are averaged, giving equal weight to the inflow of water and the outflow or removal of water.

The two parts of the equation are combined using a geometric mean based on the assumption that $V_{HYDROALT}$ is as important as the combination of the other variables in relation to water storage. In other words, if the wetland is drained to the point that it no longer has wetland hydrology, or ponds water and has been changed from a Headwater Slope wetland to a depressional or lacustrine fringe

system, then the subindex score for $V_{HYDROALT}$ would be 0.0 and the functional capacity for water storage would be zero as well.

Function 2: Cycle Organic Carbon

Definition

The function Cycle Organic Carbon is defined as the ability of the wetland to retain and transform inorganic materials needed for biological processes into organic forms and to oxidize those organic molecules back into elemental forms through decomposition. Thus, organic carbon cycling includes the biogeochemical processes of producers, consumers, and decomposers. Potential independent, quantitative measures that may be used in validating the functional index include direct measurements of net annual productivity (g/m^2), annual accumulation of organic matter (g/m^2), and annual decomposition of organic matter (g/m^2).

Rationale for selecting the function

Organic carbon cycling is a fundamental function performed by all ecosystems, but tends to be accomplished at particularly high rates in many wetland systems (Mitsch and Gosselink 2000). A sustained supply of organic carbon in the soil provides for maintenance of the characteristic plant community including annual primary productivity, composition, and diversity (Bormann and Likens 1970; Perry 1994; Whittaker 1975). The plant community (producers) provides the food and habitat structure (energy and materials) needed to maintain the characteristic animal community (consumers) (Crow and MacDonald 1978; Fredrickson 1978; Wharton et al. 1982). In time, the plant and animal communities serve as a source of detritus that is the source of energy and materials needed to maintain the characteristic community of decomposers. The decomposers break down these organic materials into simpler elements and compounds that can reenter the nutrient cycle (Dickinson and Pugh 1974; Harmon et al. 1986; Hayes 1979; Pugh and Dickinson 1974; Reiners 1972; Schlesinger 1977; Singh and Gupta 1977; Vogt et al. 1986).

Characteristics and processes that influence the function

Organic carbon cycling is a function of biotic and abiotic processes that result from conditions within and around the wetland. In wetlands, carbon is stored within and cycled among four major compartments: (a) the soil; (b) primary producers such as vascular and nonvascular plants; (c) consumers such as animals, fungi, and bacteria; and (d) dead organic matter, such as leaf litter or woody debris, referred to as detritus. Organic carbon cycling is probably best known through plants and the processes of photosynthesis and respiration. Oxygen is needed for respiration, and the rate of diffusion of oxygen in water is 1/10,000 of that in air. Wetland plants, called hydrophytes, are unique in that they have adapted to living in water or wet soil environments. Physiological adaptations in leaves, stems, and roots allow for greater gas exchange, permit respiration to take place, and allow the plant to harvest the stored chemical

energy it has produced through photosynthesis. Although there is no clear starting or ending point for carbon cycling, it can be argued that it is the presence and duration of water in the wetland that determines the characteristic plant community of hydrophytes. In turn, it is the maintenance of the characteristic primary productivity of the plant community that sets the stage for all subsequent transformations of energy and materials at each trophic level within the wetland. It follows that alterations to hydrologic inputs, outputs, or storage and/or changes to the characteristic plant community will directly affect the way in which the wetland can perform this function.

Abiotic processes affecting retention and cycling of carbon are dependent primarily on the adsorption of materials to soil particles, the amount of water that passes through the wetland carrying dissolved carbon, the hydroperiod or retention time of water that maintains anaerobic conditions, and the importation of materials from surrounding areas (Grubb and Ryder 1972; Federico 1977; Beaulac and Reckhow 1982; Ostry 1982; Shahan 1982; Strecker et al. 1992; Zarbock et al. 1994). Natural soils, hydrology, and vegetation are important factors in maintaining these characteristic processes.

The ability of a Headwater Slope wetland to perform this function depends upon the transfer of carbon between trophic levels within the wetland, the rate of decomposition, and the flux of materials in and out of the wetland. A change in the ability of one trophic level to process carbon will result in changes in the processing of carbon in other trophic levels (Carpenter 1988).

The ideal approach for assessing carbon cycling in a headwater wetland would be to measure the rate at which carbon is transferred and transformed between and within trophic levels over several years. However, the time and effort required to make these measurements are well beyond a rapid assessment procedure. Reference data suggest that land-use practices and current treatments within the wetland have great effect on the characteristic plant community structure (species composition and coverage), diversity, and primary productivity. Changes in the vegetative cover directly affect the amount of organic carbon present in the wetland. Canopy removal in particular directly affects the amount and type of detritus present in the headwater wetland. Soil texture and color value are indicators of cation exchange capacity and, therefore, indicate long-term carbon and nutrient supply and a characteristic decomposer community. Altering the texture of the soil through anthropogenic activities (e.g., filling, excavation) changes the availability of organic carbon, capacity for nutrient storage, and other factors affecting plant growth. Changes in hydrology or vegetation, deposition of fill material, excavation, or recent fire can alter the amount of soil detritus or soil organic matter. Soil organic matter is a characteristic that affects soil oxidation-reduction reactions. Soil alterations also change the physical features to which native plants have adapted. Changes to the hydrology of headwater wetlands through drainage, increased surface water flow, or ponding have a tremendous effect on carbon cycling. Increased surface water flow can sweep nearly all detrital matter from the wetland and disrupt the carbon cycle. Drainage increases the rate of decomposition of soil organic matter and, over time, changes the vegetative composition and, therefore, the type and amount of detrital matter. Ponding reduces the rate of decomposition and increases the accumulation of organic carbon, as well as changing the vegetative community.

It is assumed that measurements of these characteristics reflect the level of carbon cycling taking place within a wetland.

Functional Capacity Index

The following variables are used in the assessment model for the function Cycle Organic Carbon:

- Hydrologic Alterations ($V_{HYDROALT}$)
- Soil Detritus ($V_{DETRITUS}$)
- Surface Soil Organic Matter Content (V_{SSOM})
- Canopy Tree Diameter (V_{CTD})
- Canopy Tree Density (V_{CTDEN})
- Sapling/Shrub Cover (V_{SSC}) (This variable is used only if total tree canopy cover is <20 percent.)
- Ground Vegetation Cover (V_{GVC}) (This variable is used only if both tree and sapling/shrub cover are <20 percent.)

The assessment models for calculating the FCI for the function Cycle Organic Carbon in Headwater Slope wetlands are given in Equations 4-6. The models depend, in part, on the characteristics of the uppermost stratum of vegetation within the wetland. If the site supports a tree layer ($\geq$20 percent total tree cover), then Equation 4 is used. If the site is dominated by saplings and shrubs (<20 percent canopy cover of trees but $\geq$20 percent cover of saplings and shrubs), then Equation 5 is used. If neither trees nor saplings/shrubs are common (<20 percent cover), then Equation 6 is used.

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{DETRITUS} + V_{SSOM}}{2} \right) + \left(\frac{V_{CTD} + V_{CTDEN}}{2} \right)}{2} \right] \right\}^{1/2} \tag{4}$$

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{DETRITUS} + V_{SSOM}}{2} \right) + V_{SSC}}{3} \right] \right\}^{1/2} \tag{5}$$

$$FCI = \left\{ V_{HYDROALT} \times \left[\frac{\left(\frac{V_{DETRITUS} + V_{SSOM}}{2} \right) + V_{GVC}}{5} \right] \right\}^{1/2} \tag{6}$$

In these models, changes in the organic carbon cycling capacity of Headwater Slope wetlands relative to reference standard conditions depend on increased outflow of water or on reductions in water inflows, soil organic matter, or quantity of vegetation. The models are based on the assumption that if natural soils and vegetation are in place, and anthropogenic hydrologic disturbance is not present in the wetland, then carbon cycling will occur at an appropriate rate. In the first part of each equation, removal or retention of surface water is represented by $V_{HYDROALT}$. In the second part, $V_{DETRITUS}$ is used as an indicator of recent organic input and accumulation. If vegetation has been removed from the wetland during the previous year or two, then the amount of detritus will likely be reduced or absent. Also, if the hydrology of the wetland or adjacent watershed has been altered to the point that detritus is being flushed from the headwater ecosystem, then this alteration should be reflected in the amount of detrital cover. Surface Soil Organic Matter (V_{SSOM}) is an indication of long-term organic matter accumulation and incorporation into the soil. If hydrology or vegetation has been altered for more than a few years, then the color of the surface soil will be lighter, reflecting a decrease in organic matter content. Also, if fill material has been placed in the wetland or soil excavation has taken place, the organic matter in the previous soil surface will have been buried by the fill or removed in excavation. These two variables, $V_{DETRITUS}$ and V_{SSOM}, are combined using an arithmetic mean. This is based on the assumption that detritus and surface soil organic matter are of equal importance in cycling organic carbon. Headwater wetland vegetation is represented by the combination of V_{CTD} and V_{CTDEN}, Sapling/Shrub Cover (V_{SSC}), or Ground Vegetation Cover (V_{GVC}), whichever is representative of the tallest stratum within the headwater wetland or Wetland Assessment Area (WAA). If the amount of vegetation, represented by percentage cover, is reduced, then it is assumed that carbon cycling will be reduced. In contrast, if the amount of vegetation is greater than that found under the least disturbed natural conditions, then abnormal amounts of carbon may accumulate in the wetland and the FCI is reduced. In Equation 4, the soils and vegetative parts of the equations are averaged. In Equations 5 and 6, the two parts are divided by a factor of 3 and 5, respectively, to reflect the assumption that sites dominated by sapling/shrubs or ground vegetation do not produce or cycle carbon at the same rate as a mature forest. For a sapling/shrub-dominated wetland, the maximum FCI is 0.82. For a wetland lacking both tree and sapling/shrub strata, the maximum FCI is 0.63.

The two parts of the model are combined using a geometric mean. The implications are that if all of the variables in any part of the model equal zero, then the function would receive an FCI of zero.

Function 3: Maintain a Characteristic Plant Community

Definition

This function is defined as the degree to which a Headwater Slope wetland supports a plant community that is similar in structure and composition to that found on the least disturbed sites in the reference domain. Potential independent, quantitative measures of this function, based on species composition and relative

abundance, include similarity indices (Ludwig and Reynolds 1988) or ordination axis scores from detrended correspondence analysis or other multivariate techniques (Kent and Coker 1995). An alternative, independent, quantitative measure of this function, based on composition and abundance as well as environmental factors, is ordination axis scores from canonical correlation analysis (ter Braak 1994).

Rationale for selecting the function

The ability to maintain a characteristic plant community is important in part because of the intrinsic value of the species found there. In the Coastal Plain landscape, the dominant community type is pine flatwoods, and the Headwater Slope wetland subclass constitutes a small percentage of the overall area. Because many plant species do not occur in other landforms, their maintenance and abundance are linked to the subclass. The presence of a characteristic plant community also is critical in maintaining various biotic and abiotic processes occurring in wetlands. For example, plant communities are the source of primary productivity, produce carbon and nutrients that may be exported to other ecosystems, and provide habitats and refugia necessary for various animal species (Harris and Gosselink 1990).

Overview of the plant community

The plant communities of Headwater Slope wetlands are complex and vary across the Coastal Plain landscape and even locally. Except immediately following severe disturbances, forest is the dominant community type in the subclass. Sites that have been relatively undisturbed for decades or hundreds of years are composed of trees of various sizes and ages and generally predictable species composition. Depending on the species that initially occupy a site after a major disturbance, succession can progress along different paths. However, because of small-scale disturbances (e.g., individual trees dying and creating canopy gaps that may be colonized by different species), eventually an uneven-aged forest with well-developed stratification will be achieved (Hunter 1990). In general, older stands tend to be more stratified than younger ones, and forests with several vertical strata have higher species diversity than young or middle-aged stands with few strata (Hunter 1990; Willson 1974). This is important in maintenance of the community over time given that species diversity has been found to be positively related to community stability (Bolen and Robinson 2003).

Sites that have escaped significant disturbance for long periods normally will be dominated by trees in the larger diameter (dbh) classes. Brower and Zar (1984) noted that tree basal area (and, by inference, tree dbh) is positively correlated with stand maturity and is an indicator of time since significant disturbance (fire, catastrophic storm damage, harvest, etc.). U.S. Forest Service (1980) and Burns and Honkala (1990) are good sources of information on the maximum size that individual species of trees can attain. For many species that potentially can occupy the overstory in Headwater Slope wetlands, older trees may reach 80 cm to more than 200 cm in diameter.

Tree density is a characteristic of forest ecosystems that varies considerably throughout the life of an individual stand. In most forested systems, the density

of tree seedlings and saplings is very high following stand establishment and decreases as the forest matures and the crowns grow together to form the canopy (Spurr and Barnes 1980). Stem densities often number in the tens of thousands per hectare in the early stages of succession and normally will be reduced to a few hundred per hectare at maturity.

The species composition of Headwater Slope wetlands that have not been subjected to significant disturbance consists of native species adapted to local site conditions (i.e., soil type, hydrologic regime, etc.). One of the most common associations within the reference domain is that in which the primary overstory trees are one or more of the various species of "bays" including loblolly bay (*Gordonia lasianthus*), sweetbay (*Magnolia virginiana*), and swamp bay (*Persea palustris*). Two of the bays, sweetbay and redbay (*Persea borbonia*), along with swamp tupelo (*Nyssa biflora*), commonly form an association recognized as type 104 by the Society of American Foresters (Eyre 1980). Individual stands may include any one or all of these species (Burns and Honkala 1990). Because of the common dominance of the bay species, such wetlands frequently are referred to as bayheads (Figure 20).

Figure 20. Bays and ferns dominate this young recovering Headwater Slope wetland

Monk (1966), Gemborys and Hodgkins (1971), Nelson (1986), Wharton et al. (1977), and U.S. Army Corps of Engineers, Jacksonville District (1988), described the species composition of these Headwater Slope wetlands from various locations throughout the Southeast and are the primary sources of information for the following overview.

In the tree layer, common dominants besides the three bay species are red maple (*Acer rubrum*), Atlantic white cedar (*Chamaecyparis thyoides*), titi (*Cyrilla racemiflora*), Dahoon holly (*Ilex cassine*), slash pine (*Pinus elliottii*), pond pine (*P. serotina*), laurel oak (*Quercus laurifolia*), baldcypress (*Taxodium distichum*), and blackgum (*Nyssa sylvatica*). One species that is relatively common in forested headwater wetlands within the reference domain, but was not included in most of the accounts, is tuliptree (*Liriodendron tulipifera*). This species was mentioned as a dominant only by Gemborys and Hodgkins (1971) who noted that it normally is found in better drained sites and referred to its presence in wet areas (in southern Alabama) as "surprising." They concluded that it cannot tolerate prolonged flooding (which typically does not occur in headwater locations), but apparently is somewhat tolerant of soil saturation.

Shrub species similarly are diverse and include wax myrtle (*Morella cerifera*), Virginia willow (*Itea virginica*), fetterbush (*Lyonia lucida*), possum-haw (*Viburnum nudum)*, and large gallberry (*Ilex coriacea*). Azalea (*Rhododendron viscosum*) and titi were not mentioned as dominants in previous studies, but are common in the understory of Headwater Slope wetlands in the reference domain. It is noteworthy that many of the species in the overstory and midstory strata are evergreen.

Herbaceous species and vines that occur commonly in the understory include various ferns (e.g., Virginia chain fern (*Woodwardia virginica*), cinnamon fern (*Osmunda cinnamomea*), and netted chain fern (*Woodwardia areolata*)), yellow-eyed grasses (*Xyris* spp.), and spiderlilies (*Hymenocallis* spp.). Woody vines that sometimes are abundant include muscadine (*Vitis aestivalis*), laurel-leafed greenbriar (*Smilax laurifolia*), and poison ivy (*Toxicodendron radicans*). Sphagnum moss (*Sphagnum* spp.), royal fern (*O. regalis*), and various orchids (*Platanthera* spp.) were not mentioned in previous studies, but are common in some Headwater Slope wetlands in the reference domain.

The plant communities of Headwater Slope wetlands have been described by most authors as having a dense canopy with a tangled midstory and understory of tall shrubs and vines (Wharton et al. 1977, Nelson 1986). Braun (1950) stated that "pine and sweet bay flats with their dense tangle of shrubs and lianas interrupt the longleaf pine (*Pinus palustris*) woods." Most authors including Gemborys and Hodgkins (1971), Monk (1966), and Nelson (1986) described the understory as dense and listed numerous species that occur in the lower strata. Wharton et al. (1977), however, described the herbaceous understory of bayheads as sparse. Nelson (1986) noted that bayheads sometimes have exposed highly convoluted roots near the surface.

Some Headwater Slope wetlands in the Coastal Plain are not dominated by bays and are referred to by other names. For example, white cedar swamps (Wharton et al. 1977; Laderman 1989), hydric hammocks (Vince et al. 1989), titi swamps (U.S. Army Corps of Engineers, Jacksonville District, 1988), and Carolina bays (Laderman 1989) all are composed of similar species and are found in generally similar landscape positions. Wharton et al. (1977) indicated that the bayhead community may occur in a landscape mosaic of white cedar swamps, pond pine woodland, and pocosins. They further noted that a number of communities may grade into bay forests.

Because these wetlands and bayheads occur in similar landscape positions (depressions and drainages in headwater areas) and have similar hydrology (groundwater dominated), it is possible that they represent a continuum of types and that disturbance, particularly fire, plays a decisive role in determining point-in-time community composition.

Factors that influence the plant community

Factors that influence the development and maintenance of a characteristic plant community in most wetlands including Headwater Slope wetlands in the Coastal Plain include the physical site characteristics, the hydrologic regime, fire frequency and intensity, weather events, anthropogenic disturbances, and various ecological processes such as competition, disease, browsing pressure, shade tolerance, and community succession. Alteration to these factors or processes in the wetland or to the landscape surrounding a wetland may directly affect the species composition and biodiversity of the site (Askins et al. 1987; Keller et al. 1993; Kilgo et al. 1997). Because much of the descriptive work on plant communities of forested wetlands (and factors that influence their development and maintenance) was done in riverine systems (Robertson et al. 1978; Wharton et al. 1982; Robertson 1992; Messina and Conner 1997), less information is available regarding Headwater Slope wetlands. It is logical to infer, however, that excepting the significant differences in hydrologic inputs and processes, many of the factors that influence forested wetlands in general also are important in this subclass. These factors are well-documented in Mitsch and Gosselink (2000) and in HGM guidebooks for riverine wetlands in western Kentucky (Ainslie et al. 1999) and peninsular Florida (Uranowski et al. 2003).

An appropriate hydroperiod is one of the most important factors necessary for the development and maintenance of a characteristic plant community. In Headwater Slope wetlands, water delivery occurs as direct precipitation, overland flow, or groundwater discharge from the surroundings uplands (see Function 1). Groundwater discharge is believed to be the most important of the three in the maintenance of wetland hydrology. Activities that degrade the physical nature of a wetland, especially its hydroperiod, have the potential to have deleterious effects on the plant community and, if significant enough, may alter the plant community for extended periods, and even permanently. For example, depositing fill in a wetland fundamentally changes the substrate and hydrologic regime and, if amounts are substantial, can result in conversion of the area from wetland to nonwetland. If the site is allowed to revegetate, the ensuing plant community probably will be composed of a different suite of species, likely those with less tolerance for wetness (i.e., facultative, facultative upland and upland plants as categorized by Reed (1988)).

Some alterations that do not even occur in the wetlands themselves may have serious negative consequences for the plant community. For example, clearing the natural vegetation in the upland watershed and adding impervious surfaces (roads, parking lots, etc.) can result in significantly more water entering a wetland and likely would shift the community to one dominated by more flood-tolerant species, such as baldcypress or water tupelo. If mean water depths increase beyond the ability of even these species to survive, the area essentially would become an open water basin with vegetation existing only at the edges.

Two studies relevant to the subclass, Gemborys and Hodgkins (1971) and Nelson (1986), described the effects of forestry practices on the plant community. Gemborys and Hodgkins (1971) noted that timber extraction, particularly of slash pine and tuliptree, occurs in headwater wetlands in southern Alabama; therefore, foresters sometimes institute management practices that favor these two species over others. Nelson (1986) reported that the logging of bay trees for pulpwood has the potential to dramatically alter the structure and composition of bayhead wetlands in South Carolina.

Invasion by exotics such as Chinese privet (*Ligustrum sinense*) or Chinese tallow (*Triadica sebifera*) can result in significant changes in the species composition of Headwater Slope wetlands, particularly in the lower strata.[1] Several invasive exotics are present in the reference domain and have the potential to reduce plant community composition and diversity significantly, including Japanese honeysuckle (*Lonicera japonica*), silktree (*Albizia julibrissin*), and kudzu (*Pueraria montana*).

Except for anthropogenic impacts, Headwater Slope wetlands in the reference domain are influenced primarily by small-scale frequent disturbances, primarily individual tree mortality, which leads to gap-phase regeneration. Fire, the primary large-scale disturbance mechanism in the reference domain, does not occur frequently in the wetlands themselves because of the constantly moist environment. Forests that develop under such conditions generally are composed of shade-tolerant species of different age (and by inference size) classes (Hunter 1990).

Fire, which does occur in Headwater Slope wetlands periodically, can play a role in shaping the plant community. Wharton et al. (1977) stated that "bay forests are thought to succeed from Atlantic white cedar swamps and from gum ponds in the absence of fire and subsequent invasion by additional hardwood species." U.S. Army Corps of Engineers, Jacksonville District (1988), noted similar relationships between white cedar and bay swamps in Florida. Monk (1966, 1968) believed that bayheads are climax communities and may be "preceded (in succession) by pond pine or cypress wetlands." Fire intensity (as opposed to frequency) may be the primary factor that influences the interactions between these two communities. Wharton et al. (1977) stated that severe fires may result in bay forests reverting to Atlantic white cedar, but the role that fire plays in the dynamics between these communities is complex. The most comprehensive summary of white cedar swamps (Laderman 1989) noted that stands of cedar may be destroyed by intense fire, but "light" fire reduces competition and permits cedar reproduction. Clewell (1971) noted that bays have the ability to sprout from top-killed stumps; thus they apparently have evolved adaptations to fires that at least occasionally burn through headwater wetlands.

One way of judging the degree of disturbance to a Headwater Slope wetland is to determine the "floristic quality" of the dominant species in the plant community following the process of Andreas and Lichvar (1995). Their approach essentially integrates many influencing factors such as hydrology and soil

[1] Personal Communication, C. Henderson, 2003, Mississippi Department of Marine Resources, Biloxi, MS.

properties, successional patterns, and disturbances. They assigned different rankings to taxa present based on their degree of fidelity to synecological parameters. Plants found in many communities including disturbed sites, were assigned rankings of 1 to 3. Plants associated with specific communities but that tolerate moderate disturbance were assigned rankings of 4 to 6. Plants associated with advanced successional stages that have undergone relatively minor disturbance were assigned rankings of 7 to 8. Plants with a high degree of fidelity to a narrow range of synecological parameters were assigned values of 9 to 10. The latter two categories typically will comprise species that are tolerant to very tolerant of shade (i.e., they can persist in the understory and thus are present and can "capture" gaps in the canopy when they do occur). In the reference domain, common dominants in Headwater Slope wetlands that are shade tolerant include redbay, red maple, and laurel oak (Burns and Honkala 1990). Thus, older stands in which little disturbance has occurred likely will include one or more of these species as dominant canopy trees.

Functional Capacity Index

The following variables are used in the assessment model for the function Maintain a Characteristic Plant Community:

- Canopy Tree Diameter (V_{CTD})
- Canopy Tree Density (V_{CTDEN})
- Vegetation Composition and Diversity (V_{COMP})
- Sapling/Shrub Cover (V_{SSC}) (This variable is used only if total tree canopy cover is <20 percent.)
- Ground Vegetation Cover (V_{GVC}) (This variable is used only if tree and sapling/shrub cover are both <20 percent.)

The assessment models for calculating the FCI for the maintenance of a characteristic plant community in Headwater Slope wetlands are given in the following equations. The models depend on the characteristics of the uppermost stratum of vegetation present within the wetland. If the site contains a tree layer ($\geq$20 percent total tree cover), then Equation 7 is used. If the site is dominated by saplings and shrubs (<20 percent cover of trees but $\geq$20 percent cover of saplings and shrubs), then Equation 8 is used. If neither trees nor saplings/shrubs are common (<20 percent cover), then Equation 9 is used.

$$FCI = \left(\frac{\frac{V_{CTD} + V_{CTDEN}}{2} + V_{COMP}}{2} \right) \tag{7}$$

$$FCI = \left(\frac{V_{SSC} + V_{COMP}}{4} \right) \tag{8}$$

$$FCI = \left(\frac{V_{GVC} + V_{COMP}}{6} \right) \tag{9}$$

These models represent the existing plant community in the wetland and include variables that provide insight into its seral stage, structure, species composition, diversity, and stability. The models assume that the physical environment necessary to maintain the community (e.g., hydrology, soil characteristics) is also present. If not, any recent environmental changes that may affect the long-term persistence of the community should be reflected in reduced FCIs for Functions 1 and 2. In the context of this function, canopy tree diameter (V_{CTD}) and density (V_{CTDEN}) are structural indicators of seral stage and of disturbance. The vegetation composition and diversity variable (V_{COMP}) reflects floristic quality and diversity, as well as seral stage and disturbance. In a forested wetland (Equation 7), subindices for V_{CTD} and V_{CTDEN} are averaged before being combined with V_{COMP}. V_{CTD} and V_{CTDEN} cannot go to 0.0 if trees are present; therefore, the FCI will always be greater than zero if trees are present. In Equations 8 and 9, the two variables are divided by a factor of 4 or 6, respectively, under the assumption that sites dominated by saplings/shrubs or ground vegetation do not provide the level of function provided by a mature forest community, even if succession will tend toward that condition eventually. For a sapling/shrub-dominated wetland, the maximum FCI is 0.50. For a wetland lacking both tree and sapling/shrub strata, the maximum FCI is 0.33.

Function 4: Provide Characteristic Wildlife Habitat

Definition

This function is defined as the capacity of a Headwater Slope wetland to provide critical life requisites to selected components of the vertebrate wildlife community. Wetlands within the subclass provide habitat for numerous species of amphibians, reptiles, birds, and mammals. Birds and amphibians were selected as the focus of this function. Birds were chosen because they are of considerable public and agency interest, and they respond rapidly to changes in the quality and quantity of their habitats. In addition, birds are a diverse group, and individual species have strong associations with the different strata of the multilayered forests that characterize reference standard Headwater Slope wetlands. Birds have been shown to be sensitive indicators and integrators of environmental change such as that brought about by human use and alteration of landscapes (Morrison 1986; Croonquist and Brooks 1991; O'Connell et al. 2000). Amphibians were chosen because of the importance of wetlands as breeding habitat. Various species of salamanders and frogs breed in shallow streams, temporary ponds, and moist leaf litter or duff. In the adult stages, they often disperse into suitable habitat in the adjacent uplands.

A potential independent, quantitative measure of this function that could be used to validate the assessment model (Wakeley and Smith 2001) is the combined species richness of birds and amphibians that use Headwater Slope

wetlands throughout the annual cycle. Data requirements for model validation include direct monitoring of wildlife communities using appropriate techniques for each taxon. Ralph et al. (1993) described field methods for monitoring bird populations. Gibbons and Semlitsch (1981) described procedures for sampling small animals including reptiles and amphibians. Heyer et al. (1994) and Dodd (2003) described monitoring procedures for amphibians.

Rationale for selecting the function

Wetlands are recognized as valuable habitats for a diversity of animal species including both vertebrates and invertebrates. For example, songbirds, such as the prothonotary warbler (*Protonotaria citrea*) and Acadian flycatcher (*Empidonax virescens*), are associated with forested wetlands within the reference domain and provide recreational opportunities for birdwatchers and nature enthusiasts. Further, because birds are highly mobile, they serve as a transfer mechanism for nutrients and energy from wetlands to other ecosystems. Several mammals, including the mink (*Mustela vison*) and raccoon (*Procyon lotor*), also are closely associated with wetlands and similar environments. They are important predators in wetlands and riparian areas and, as such, play key roles in ecosystem structure and stability. Amphibians are common in most wetland ecosystems, but many are secretive and seldom seen. In some situations, they can be extremely abundant. Burton and Likens (1975) reported that amphibians constitute the single largest source of vertebrate biomass in some ecosystems. Because many amphibians require both wetland and adjacent upland habitats, they serve as a conduit for energy exchange between the two systems (Bailey et al. 2006). Wharton et al. (1982), Johnson (1987), Whitlock et al. (1994), Mitsch and Gosselink (2000), and Bailey et al. (2006) are all good sources of information regarding animal communities of wetlands.

Many wildlife species associated with wetlands have experienced serious population declines. Within the United States, approximately one third of the plant and animal species listed as threatened or endangered are associated with wetlands during some part of their life cycles (Dahl and Johnson 1991). Headwater Slope wetlands constitute a relatively small percentage of the landscape within the reference domain, and the upland matrix in many areas is dominated by agricultural land, managed forests, and residential and commercial development. Therefore, Headwater Slope wetlands likely are important for the maintenance of local populations of many species.

Overview of the wildlife community

Within the reference domain, numerous game and non-game species from four vertebrate classes commonly use Headwater Slope wetlands for shelter, as breeding or foraging areas, or as sources of drinking water. This general discussion includes information about reptiles and mammals although, as noted previously, birds and amphibians are the focus of the wildlife model.

Avian species use Headwater Slope wetlands throughout the year, although some species are present only periodically. Common year-round residents include the Carolina chickadee (*Poecile carolinensis*), tufted titmouse (*Baeolophus bicolor*), Carolina wren (*Thryothorus ludovicianus*), blue-gray

gnatcatcher (*Polioptila caerulea*), blue jay (*Cyanocitta cristata*), northern cardinal (*Cardinalis cardinalis*), and red-bellied woodpecker (*Melanerpes carolinus*). Species such as the great crested flycatcher (*Myiarchus crinitus*), eastern wood-peewee (*Contopus virens*), Kentucky warbler (*Oporornis formosus*), and summer tanager (*Piranga rubra*) breed in wetlands within the subclass, but winter primarily in tropical areas. Other species do not breed in the reference domain, but winter there and may use Headwater Slope wetlands during that period. Some examples include the yellow-bellied sapsucker (*Sphyrapicus varius*), ruby-crowned kinglet (*Regulus calendula*), black-and-white warbler (*Mniotilta varia*), and yellow-rumped warbler (*Dendroica coronata*). During the spring and fall migration periods, numerous species of neotropical migrants use Headwater Slope wetlands as "stopover" habitat. Wharton et al. (1982), Hamel (1992), and Boynton (1994) contain information about avian communities in wetlands in the Southeast.

Bailey et al. (2006) described the habitats important to amphibians and reptiles and their management in the Southeast. Some of the species they considered characteristic of springs and seepage areas (the habitat type they described that is most like Headwater Slope wetlands) included the spotted dusky salamander (*Desmognathus conanti*), southern two-lined salamander (*Eurycea cirrigera*), green frog (*Rana clamitans*), southern leopard frog (*R. sphenocephala*), southern water snake (*Nerodia fasciata*), and queen snake (*Natrix septemvittata*). See Mount (1975) and Conant and Collins (1991) for additional information on amphibians and reptiles in the reference domain.

Several mammals routinely use Headwater Slope wetlands within the reference domain. Some species (or their sign) were observed during the development of this guidebook. These included the raccoon, eastern cottontail rabbit (*Sylvilagus floridanus*), gray squirrel (*Sciurus carolinensis*), and white-tailed deer (*Odocoileus virginianus*). These and many other species of medium- to large-sized mammals that occur in the reference domain (e.g., mink, opossum (*Didelphis marsupialis*), and gray fox (*Urocyon cinereoargenteus*)) likely use Headwater Slope wetlands as foraging sites or as sources of drinking water. The mink and raccoon, especially, are known to be associated with wetland habitats. Several chiropterans, including the red bat (*Lasiurus borealis*) and evening bat (*Nycticeius humeralis*), occur within the reference domain and favor wetlands as foraging habitat.[1] Small mammals such as mice, voles, and shrews often use a variety of habitats, but two, the golden mouse (*Ochrotomys nuttalli*) and southeastern shrew (*Sorex longirostris*), tend to be associated with wetlands and occur throughout the reference domain (Kays and Wilson 2002).

Characteristics and processes that influence the function

Hydrologic alteration of Headwater Slope wetlands has the potential to impact a number of wildlife species, but the most serious impacts would be to amphibians. Animals with direct dependence on water, such as amphibians that use seasonally ponded microdepressions within Headwater Slope wetlands for reproduction, are highly vulnerable to wetland drainage (e.g., by ditching) or

[1] Personal Communication, M. J. Harvey, 2004, Tennessee Technological University, Cookeville, TN.

filling of wetlands for human developments. Even partial draining or filling could impact breeding activity because of the length of time needed for egg development and maturation of the young. There is considerable variability in development time among species. Most anurans require the presence of water for 2 to 3 months (Duellman and Trueb 1986). Some species, however, require substantially shorter periods of time. The eastern spadefoot toad (*Scaphiopus holbrooki holbrooki*), for example, needs only 2 to 3 weeks to mature.[1] Conversely, artificially increasing the amount of time that surface water is present in a wetland by excavating or by augmenting runoff into the wetland can potentially reduce the suitability for amphibians by allowing fish populations to become established. Bailey et al. (2006) noted that predatory fish prey on breeding amphibians, their eggs, and tadpoles. They recommended that wherever wetlands free of fish exist, efforts should be made to avoid accidental or deliberate introductions.

Besides the direct effects of hydrologic change on animals, indirect effects can occur through changes in the plant community. Sites with unaltered hydrology that have not been subjected to significant disturbance for long periods support a characteristic vegetation composition and structure (i.e., tree size, density, stratification, etc.) as described in the plant community model. Wildlife species have evolved with and adapted to these conditions. Thus, altering the hydroperiod has the potential to change the composition and structure of the wildlife community. Factors other than hydrology, including droughts and catastrophic storms, fire frequency and intensity, competition, disease, browsing pressure, shade tolerance, community succession, and natural and anthropogenic disturbances, also affect the plant community directly and wildlife community indirectly. Following is an overview of the relationships between specific characteristics of the plant community and wildlife utilization of forested ecosystems including wetlands. Wharton et al. (1982), Hunter (1990), and Morrison et al. (1992) are all good sources of information on this subject.

Habitat structure is probably the most important determinant of wildlife species composition and diversity (Wiens 1969; Anderson and Shugart 1974). This is especially well documented with birds, which tend to show affinities for habitats based on physical characteristics, such as the size and density of overstory trees, density of shrub and ground cover, number of snags, and other factors. MacArthur and MacArthur (1961) first documented the positive relationship between the vertical distribution of foliage (i.e., the presence of different layers or strata) and avian diversity, and other researchers have since corroborated their findings. For example, Ford's (1990) study of birds and their habitats in bottomland hardwood wetlands supported the importance of community structure to the majority of species that were common at his study sites during the breeding season. Many of these same species also occur in Headwater Slope wetlands within the reference domain. Hunter (1990) provided a good overview of the importance of plant community structure to wildlife.

Undisturbed Headwater Slope wetlands within the reference domain normally contain multiple strata. This structural complexity provides a myriad of habitat conditions for animals and allows numerous species to coexist in the same

[1] Personal Communication, M. A. Bailey, 2004, Conservation Southeast, Inc., Andalusia, AL.

area (Schoener 1986). For example, some bird species utilize the forest canopy, whereas others are associated with the understory (Cody 1985; Wakeley and Roberts 1996). Structural characteristics of forested ecosystems (e.g., tree size, tree density, and understory cover) are easily measured and are reliable indicators of habitat quality for birds. Similar measures of vegetation structure have been used in various Habitat Suitability Index (HSI) models (Schroeder 1985; Allen 1987) and in other HGM guidebooks (Ainslie et al. 1999; Smith and Klimas 2002). They are discussed briefly in the following paragraphs.

Tree size is an indicator of forest maturity (Brower and Zar 1984; DeGraaf et al. 1992) and, in most cases, structural complexity (Hunter 1990). Older undisturbed Headwater Slope wetlands dominated by large trees provide resources that areas dominated by smaller trees cannot. For example, large trees are more likely to develop natural cavities or be attacked by cavity excavators. Cavities provide shelter and nesting sites for gray squirrels, red-bellied woodpeckers, and other species. In forests containing oaks, age is an important factor in acorn production. Although there is considerable variation among species, most oaks do not begin producing acorns until they are at least 25 cm (10 in.) in diameter (U.S. Forest Service 1980). Older forests dominated by large trees also typically have distinct strata, including a tree canopy, a woody understory composed of saplings and shrubs, and a herbaceous or ground layer. Young forests composed of sapling to pole-sized trees tend to be less stratified.

Tree density also is an indicator of forest maturity and time since significant disturbance. In most forested systems, the density of tree seedlings and saplings is very high following stand establishment and decreases as the forest matures (Spurr and Barnes 1980; Hunter 1990; DeGraaf et al. 1992). Stem densities often number in the tens of thousands per hectare in the early stages of succession and normally are reduced to a few hundred per hectare at maturity. In undisturbed mature forested wetlands within the reference domain, the crowns grow relatively close together. Reducing tree density, such as through timber harvesting, reduces crown volume and results in a direct loss of fruit production and foraging space for insectivorous birds. Canopy cover also affects the lower strata by controlling the amount of sunlight that reaches the forest floor. Generally, there is an inverse relationship between canopy cover and understory density (Hunter 1990).

A well-developed sapling/shrub layer (i.e., woody stems <10 cm (4 in.) dbh) is present in most undisturbed Headwater Slope wetlands and has a significant influence on the wildlife community. Bird species that are closely associated with the sapling/shrub layer include the northern cardinal, Carolina wren, brown thrasher (*Toxostoma rufum*), white-eyed vireo (*Vireo griseus*), Kentucky warbler, and hooded warbler (*Wilsonia citrina*). Roberts and Peterson (2001) found both bird abundance and species richness to be positively correlated with percenttage shrub cover in depression and flat wetlands in central Tennessee. It is likely that a similar relationship exists for wetlands in the Headwater Slope subclass.

Land use surrounding the wetland also has a major impact on the wetland wildlife community. Historically, the reference domain was largely forested. The wildlife community evolved in a landscape with wetlands surrounded by vast tracts of open woods and savannas maintained by frequent fires. With fire

suppression during recent times, many upland forests on the Coastal Plain have become more crowded with undergrowth and increasingly dominated by hardwoods.

Human activities have dramatically altered the reference domain in other ways as well. Currently much of it is devoted to commercial pine plantations, crop production and pasture, residential and commercial developments, and other open land uses. Consequently, Headwater Slope wetlands often occur now as isolated patches within an open landscape matrix. Adverse effects of the “fragmentation” of formerly forested landscapes have been especially well documented for avian species and communities (Askins et al. 1987; Keller et al. 1993; Kilgo et al. 1997) and for reptiles and amphibians (Laan and Verboon 1990; Semlitsch 1998; Semlitsch and Jensen 2001; Rothermel and Semlitsch 2002; Bailey et al. 2006). Research into the effects of fragmentation on mammals has been less common (Nilon 1986; VanDruff and Rowse 1986; Nilon and VanDruff 1987).

Biological and genetic diversity are reduced as habitat fragmentation and urbanization occur in an area. Larger and more specialized animal species, especially those having large home ranges, are affected from the onset of the fragmentation (VanDruff et al. 1996). Habitat specialists are often the first to be extirpated from an area or region. Eventually, however, even generalist species are impacted if fragmentation is extreme. Urbanization often accompanies habitat fragmentation. Urbanization reduces the number of native wildlife species in an area, while increasing the abundance of exotic species (VanDruff et al. 1996; McKinney 2002).

Although tied to wetlands and other aquatic habitats for breeding, many southeastern frogs and some salamanders spend the remainder of the year in terrestrial habitats, often in hardwood forests (Bailey et al. 2006). Semlitsch and Jensen (2001) noted that suitable terrestrial habitat surrounding the breeding site is critical for feeding, growth, maturation, and maintenance of juvenile and adult populations of pond-breeding salamanders. Bailey et al. (2006) concurred, stating that “a seasonal wetland without appropriate surrounding upland habitat will lose its amphibian and reptile fauna.” Semlitsch and Jensen (2001) suggested that the terrestrial habitat be referred to as part of the “core habitat” used by the animals, because it is as essential as the breeding site itself. This is different from the traditional concept of the “buffer zone” commonly recommended around wetlands to protect various wetland functions (Boyd 2001).

Semlitsch and Bodie (2003) reviewed the literature on terrestrial habitats used by amphibians. Habitat features such as leaf litter, coarse woody debris (i.e., logs), boulders, small mammal burrows, cracks in rocks, spring seeps, and rocky pools were important for foraging, refuge, or overwintering. A well-developed canopy (for shade) and coarse woody debris and litter (for refuge and food) were considered to be essential habitat features. The abundance of litter is related to the age of forest stands. The litter layer in an older forest usually is much thicker than in a younger forest due to the differential amount of foliage produced. Young stands do not begin to contain significant amounts of litter and coarse woody debris until natural thinning begins. Coffey (1998) reported that minimal woody debris was found in bottomland hardwood stands younger than 6 years of

age. Such a pattern probably also exists in upland forests. Shade, which is critical to some amphibian species in slowing or preventing dehydration (Spight 1968, Rothermel and Semlitsch 2002), is provided to some extent in all forest stands but likely is not effective until tree canopies begin to close (Rothermel and Semlitsch 2002). In the absence of more specific information regarding how amphibians might respond to different conditions, it is assumed here that nearly all forested areas, savannas, sapling/shrub habitats, and native prairie will provide at least minimally suitable terrestrial habitat for dispersing amphibians. Managed pine forest is considered suitable only if soils, litter, and ground-layer vegetation have not been disturbed extensively (e.g., by bedding) such that cover has been eliminated and animal movement impeded. Areas devoted to row crops and closely mowed or grazed pastures are not suitable (Boyd 2001).

In addition to the structural characteristics of contiguous habitats, the size of such areas also is important to many amphibian and reptile species. The width of suitable contiguous habitat needed for any given wetland area depends upon a number of variables including wetland size, topography, climate, surrounding land use, and the species of herpetofauna present (Semlitsch and Jensen 2001). Boyd (2001) compiled information regarding animal use of areas adjacent to wetlands to evaluate the adequacy of the Massachusetts Wetland Protection Act. She concluded that the 30-m (100-ft) buffer required by the Act provided protection for 77 percent of the species known to be dependent on wetlands, but recommended that even larger areas be considered because numerous species sometimes travel much greater distances. Semlitsch and Bodie (2003) synthesized the literature on terrestrial habitats used by amphibians and reptiles associated with wetlands, and concluded that core terrestrial habitat extends 159 to 290 m (522 to 950 ft) from the wetland edge for most amphibians and 127 to 289 m (417 to 948 ft) for most reptiles, although some species may move much farther. For example, certain frogs sometimes move up to 1,600 m (5,250 ft) from the aquatic edge. The mean maximum distances moved (calculated from numerous studies of various herpetofauna) for various groups included 218 m (715 ft) for salamanders considered separately from other amphibians, 368 m (1,207 ft) for frogs, 304 m (997 ft) for snakes, and 287 m (942 ft) for turtles.

Terrestrial areas immediately adjacent to wetlands also are important to the integrity of the wetland ecosystem itself. Such areas serve to reduce the amounts of silt, contaminants, and pathogens that enter the wetland, and to moderate physical parameters such as temperature (Rhode et al. 1980; Young et al. 1980; Hupp et al. 1993; Snyder et al. 1995; Daniels and Gilliam 1996; Semlitsch and Jensen 2001; Semlitsch and Bodie 2003). These functions directly or indirectly affect amphibians through improved water quality and provide benefits to the entire wildlife community. Semlitsch and Bodie (2003) recommended a 30- to 60-m- (100- to 200-ft-) wide buffer around the wetland for this purpose alone.

Birds also are known to be impacted adversely by habitat fragmentation, which leads to increased predation, nest parasitism by the brown-headed cowbird (*Molothrus ater*), and possibly other factors (Askins et al. 1987; Keller et al. 1993; Kilgo et al. 1997). Several of the species associated with Headwater Slope wetlands and adjacent forests within the reference domain are considered “interior” (Hamel 1992) or “area-sensitive” species (Robbins et al. 1989). Area-sensitive species tend to have lower reproductive output in smaller habitat

patches or they simply avoid small patches altogether.[1] While landscape considerations are important for birds as well as amphibians, there is a substantial difference in scale, with patch size requirements for some individual bird species exceeding 5,000 ha (12,355 acres). Given the current land use and small size of most Headwater Slope wetlands within the reference domain, focusing the landscape-level variables in the model entirely on birds is impractical. Although having sufficient core habitat for amphibians may not entirely eliminate adverse effects of fragmentation, it should be useful in protecting birds from nest parasitism and predation by animals associated with edges. Most impacts on birds are thought to occur relatively close to an edge (within 100 to 300 m (328 to 984 ft)) (Brittingham and Temple 1983; Strelke and Dickson 1980; Wilcove 1985).

Functional Capacity Index

The following variables are used in the assessment model for the function Provide Characteristic Wildlife Habitat:

- Hydrologic Alterations ($V_{HYDROALT}$)
- Change in Catchment Size (V_{CATCH})
- Upland Land Use (V_{UPUSE})
- Canopy Tree Diameter (V_{CTD})
- Canopy Tree Density (V_{CTDEN})
- Habitat Connections ($V_{CONNECT}$)
- Sapling/Shrub Cover (V_{SSC}) (This variable is used only if total tree cover is <20 percent.)
- Ground Vegetation Cover (V_{GVC}) (This variable is used only if tree and sapling/shrub cover are both <20 percent.)

The model for deriving the FCI for the wildlife habitat function of Headwater Slope wetlands depends, in part, on the characteristics of the uppermost stratum of vegetation within the wetland. If the site supports a tree layer ($\geq$20 percent total tree cover), then Equation 10 is used. If the site is dominated by saplings and shrubs (<20 percent cover of trees but $\geq$20 percent cover of saplings and shrubs), then Equation 11 is used. If neither trees nor saplings/shrubs are common (<20 percent cover), then Equation 12 is used.

$$FCI = \left[\left(V_{HYDROALT} \times \left\{ \frac{V_{CATCH} + V_{UPUSE}}{2} \right\} \right)^{1/2} \times \left(\frac{\left\{ \frac{V_{CTD} + V_{CTDEN}}{2} \right\} + V_{CONNECT}}{2} \right) \right]^{1/2} \quad (10)$$

$$FCI = \left[\left(V_{HYDROALT} \times \left\{ \frac{V_{CATCH} + V_{UPUSE}}{2} \right\} \right)^{1/2} \times \left(\frac{V_{SSC} + V_{CONNECT}}{5} \right) \right]^{1/2} \quad (11)$$

[1] Personal Communication, D. A. Buehler, 2004, University of Tennessee, Knoxville.

$$FCI = \left[\left(V_{HYDROALT} \times \left\{ \frac{V_{CATCH} + V_{UPUSE}}{2} \right\} \right)^{1/2} \times \left(\frac{V_{GVC} + V_{CONNECT}}{10} \right) \right]^{1/2} \tag{12}$$

This model is assumed to reflect the ability of Headwater Slope wetlands to provide critical life requisites for wildlife, with an emphasis on amphibians and birds. If the components of this model are similar to those found under reference standard conditions, then it is likely that the entire complement of amphibians and birds characteristic of Headwater Slope wetlands within the reference domain will be present.

The first part of each equation is an expression of the hydrologic integrity of the wetland and involves variables $V_{HYDROALT}$, V_{CATCH}, and V_{UPUSE}. In the context of this function, a characteristic hydrologic regime is essential as a source of water for breeding amphibians and to support the plant community upon which the animal community depends. The second part of each equation contains variables that reflect seral stage, cover potential, food production potential, nest site potential, availability of dispersal habitat, and other factors that depend on stand structure, maturity, and connectivity. V_{CTD} and V_{CTDEN} are used when the wetland is dominated by trees; V_{SSC} is used in sapling/shrub-dominated wetlands; and V_{GVC} is used in wetlands lacking sufficient trees or shrubs. Other features of forested wetlands such as snags, logs, and leaf litter also are important habitat requirements for various members of the wildlife community, but are not explicitly included in the model. It was assumed that if the structure and composition of the overstory and shrub layer are appropriate, then these additional features will be present in the appropriate numbers or amounts. The final variable in each equation is $V_{CONNECT}$, which represents the availability of suitable habitat beyond the wetland boundary. This terrestrial buffer helps protect wetland water quality, provides critical habitat for some species of amphibians, and is important in protecting some species of birds from nest predators and parasites. Hydrologic integrity is assumed to be critical to the maintenance of wetland wildlife habitat; therefore, the hydrology component is used as a multiplier in each equation. The other terms in the model, which reflect onsite and offsite habitat conditions, are assumed to be partially compensatory (i.e., a low value for one term will be partially compensated by a high value for the other(s)). In Headwater Slope wetlands dominated by trees, the maximum possible FCI is 1.0. Wetlands dominated by saplings and shrubs and few or no large trees are assumed to have lower value for birds and amphibians; the maximum FCI in sapling/shrub wetlands is 0.63. In wetlands containing few trees or shrubs, the maximum FCI is 0.45.

5 Assessment Protocol

Introduction

Previous chapters of this Regional Guidebook provide background information on the HGM Approach, and document the variables, measures, and models used to assess the functions of Headwater Slope wetlands. This chapter outlines a protocol for collecting and analyzing the data necessary to assess the functional capacity of a wetland in the context of a Section 404 permit review or similar assessment scenario. The typical assessment scenario is a comparison of pre-project and post-project conditions in the wetland. In practical terms, this translates into an assessment of the functional capacity of the WAA under both pre-project and post-project conditions and the subsequent determination of how FCIs have changed as a result of the project. Data for the pre-project assessment are collected under existing conditions at the project site, while data for the post-project assessment are normally based on the conditions expected to exist following proposed project impacts. A skeptical, conservative, and well-documented approach is required in defining post-project conditions. This recommendation is based on the often-observed lack of similarity between predicted or engineered post-project conditions and actual post-project conditions. This chapter discusses each of the following tasks required to complete an assessment of Headwater Slope wetlands:

a. Define assessment objectives.

b. Characterize the project area.

c. Screen for red flags.

d. Define the Wetland Assessment Area.

e. Determine the wetland subclass.

f. Collect the data.

g. Analyze the data.

h. Apply assessment results.

Define Assessment Objectives

Begin the assessment process by unambiguously identifying the purpose of the assessment. This can be as simple as stating, “The purpose of this assessment is to determine how the proposed project will impact wetland functions.” Other potential objectives could be as follows:

a. Compare several wetlands as part of an alternatives analysis.

b. Identify specific actions that can be taken to minimize project impacts.

c. Document baseline conditions at a wetland site.

d. Determine mitigation requirements.

e. Determine mitigation success.

f. Determine the effects of a wetland management technique.

Frequently, multiple reasons are identified for conducting an assessment. Carefully defining the purpose(s) facilitates communication and understanding among the people involved in the assessment, and makes the goals of the study clear to other interested parties. In addition, defining the purpose helps to clarify the approach that should be taken. The specific approach will vary to some degree depending upon whether the project is a Section 404 permit review, an Advanced Identification (ADID), Special Area Management Plan (SAMP), or some other scenario.

Characterize the Project Area

Characterizing the project area involves describing the area in terms of climate, surficial geology, geomorphic setting, surface and groundwater hydrology, vegetation, soils, land use, proposed impacts, and any other characteristics and processes that have the potential to influence how wetlands in the project area perform functions. The characterization should be written and accompanied by maps and figures that show project area boundaries, jurisdictional wetlands, the boundaries of the WAA (discussed later in this chapter), proposed impacts, roads, ditches, buildings, streams, soil types, plant communities, threatened or endangered species habitat, and other important features. Some sources of information useful in characterizing a project area are aerial photographs, topographic and National Wetland Inventory (NWI) maps, and county soil surveys.

Screen for Red Flags

Red flags are features within or in the vicinity of the project area to which special recognition or protection has been assigned on the basis of objective criteria (Table 8). Many red flag features, such as those based on national criteria or programs, are similar from region to region. Other red flag features are based on regional or local criteria. Screening for red flag features represents a proactive attempt to determine if the wetlands or other natural resources in and around the project area require special consideration or attention that may preempt or postpone an assessment of wetland functions. An assessment of wetland functions may not be necessary if the project is unlikely to occur as a result of a red flag feature. For example, if a proposed project has the potential to impact a threatened or endangered species or habitat, an assessment of wetland functions may be unnecessary since the project may be denied or modified strictly on the basis of the impacts to threatened or endangered species or habitat.

Table 8 Red Flag Features and Respective Program/Agency Authority	
Red Flag Features	**Authority**[1]
Native Lands and areas protected under American Indian Religious Freedom Act	A
Hazardous waste sites identified under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Resource Conservation and Recovery Act (RCRA)	I
Areas protected by a Coastal Zone Management Plan	E
Areas providing Critical Habitat for Species of Special Concern	B, C, F
Areas covered under the Farmland Protection Act	K
Floodplains, floodways, or floodprone areas	J
Areas with structures/artifacts of historic or archeological significance	G
Areas protected under the Land and Water Conservation Fund Act	K
Areas protected by the Marine Protection Research and Sanctuaries Act	B, D
National wildlife refuges and special management areas	C
Areas identified in the North American Waterfowl Management Plan	C, F
Areas identified as significant under the Ramsar Treaty	H
Areas supporting rare or unique plant communities	C, H
Areas designated as Sole Source Groundwater Aquifers	I, L
Areas protected by the Safe Drinking Water Act	I, L
City, County, State, and National Parks	D, F, H, L
Areas supporting threatened or endangered species	B, C, F, H, I
Areas with unique geological features	H
Areas protected by the Wild and Scenic Rivers Act	D
Areas protected by the Wilderness Act	D

[1]Program Authority / Agency
A = Bureau of Indian Affairs
B = National Marine Fisheries Service
C = U.S. Fish and Wildlife Service
D = National Park Service
E = State Coastal Zone Office
F = State Departments of Natural Resources, Fish and Game, etc.
G = State Historic Preservation Office
H = State Natural Heritage Offices
I = U.S. Environmental Protection Agency
J = Federal Emergency Management Agency
K = Natural Resources Conservation Service
L = Local Government Agencies

Define the Wetland Assessment Area

The WAA is an area of wetland within a project area that belongs to a single regional wetland subclass and is relatively homogeneous with respect to the site-specific criteria used to assess wetland functions (i.e., hydrologic regime, vegetation structure, topography, soils, successional stage, etc.). In many project areas, there will be just one WAA representing a single wetland subclass, as illustrated in Figure 21. However, as the size and heterogeneity of the project area increase, it may be necessary to define and assess multiple WAAs or Partial Wetland Assessment Areas (PWAAs) within the project area.

At least three situations necessitate defining and assessing multiple WAAs or PWAAs within a project area. The first situation exists when widely separated

wetland patches of the same regional subclass occur in the project area (Figure 22). The second situation exists when more than one regional wetland subclass occurs within a project area (Figure 23). The third situation exists when a physically contiguous wetland area of the same regional subclass exhibits spatial heterogeneity with respect to hydrology, vegetation, soils, disturbance history, or other factors that translate into a significantly different value for one or more of the site-specific variable measures. These differences may be a result of natural variability (e.g., zonation on large river floodplains) or cultural alteration (e.g., logging, surface mining, hydrologic alterations) (Figure 24). Designate each of these areas as a separate PWAA and conduct a separate assessment on each area.

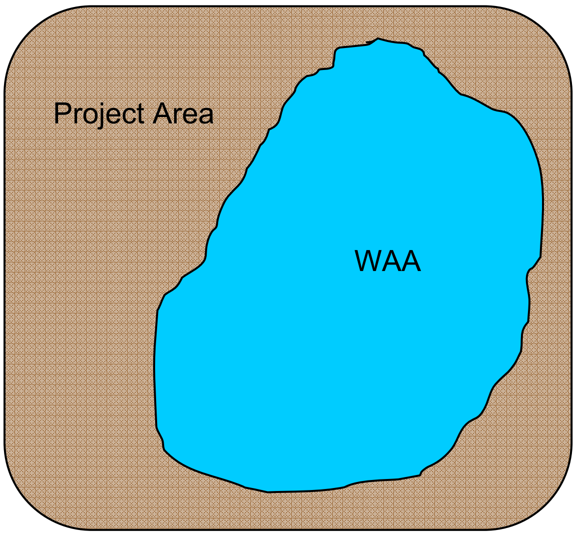

Figure 21. A single WAA within a project area

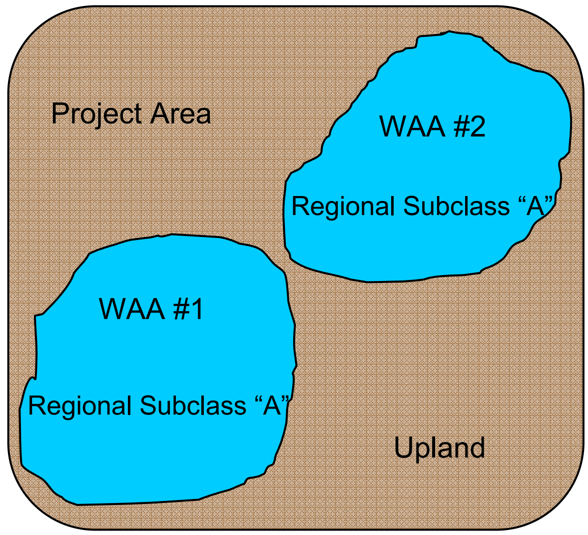

Figure 22. Spatially separated WAAs from the same regional subclass within a project

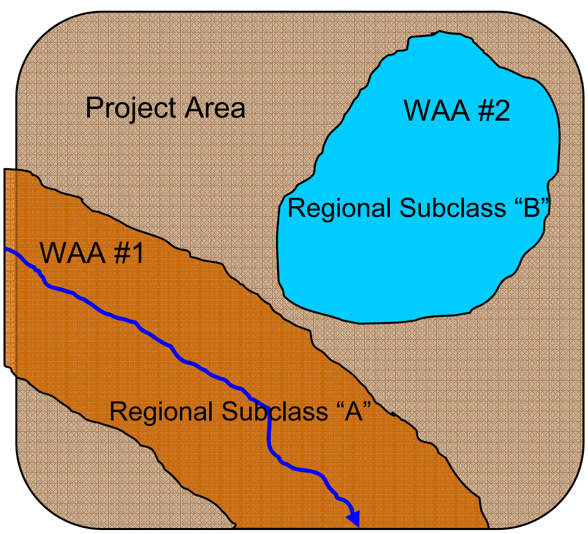

Figure 23. More than one regional subclass within a project area

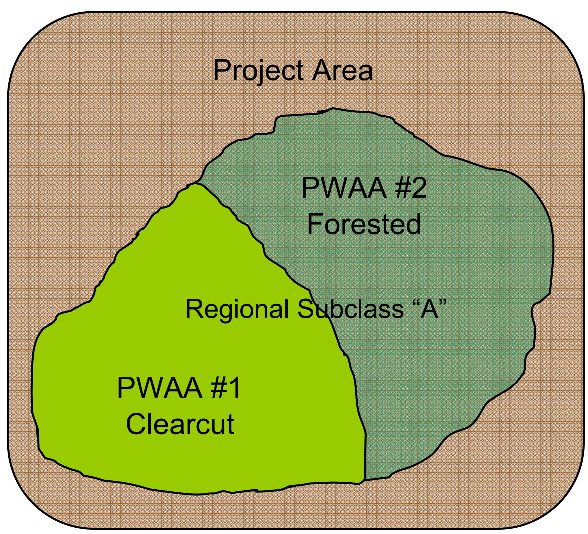

Figure 24. PWAAs defined on the basis of differences in site-specific characteristics

There are elements of subjectivity and practicality in determining what constitutes a significant difference in portions of the WAA. Field experience with the regional wetland subclass under consideration should provide a sense of the range of variability that typically occurs, and the understanding necessary to make reasonable decisions about defining multiple PWAAs. For example, in Headwater Slope wetlands, recent logging in a portion of a wetland area may be a criterion for designating two PWAAs. The presence of relatively minor differences resulting from natural variability should not be used as a basis for dividing a contiguous wetland into multiple PWAAs. However, zonation caused by different hydrologic regimes or disturbances caused by rare and destructive natural events (e.g., hurricanes) should be used as a basis for defining PWAAs.

Determine the Wetland Subclass

This guidebook describes Headwater Slope wetlands found in southern Mississippi and Alabama. Determining the correct subclass is essential to completing a meaningful HGM assessment. Subclasses are based on hydrogeomorphic characteristics. Headwater Slope wetlands in the reference domain were defined previously as headwater wetlands, including those associated with first-order streams, that are supported by precipitation and groundwater inputs from the surrounding uplands and are not dominated by riverine processes. Current aerial photographs, topographic maps, soils maps, NWI maps, local knowledge, or other available information can be used to help identify Headwater Slope wetlands and distinguish them from riverine (floodplain) systems. In some cases, however, it will not be possible to determine the wetland subclass from remotely sensed data or maps, and onsite investigation will be necessary. Some extremely disturbed sites will be difficult to evaluate even during an onsite examination. In these cases, historical aerial photographs or knowledge of local experts may be helpful in determining the wetland subclass.

Collect Field Data

The first step in data collection is to identify and delineate the project area and WAA or PWAAs on aerial photographs and topographic maps. Always use the most recent and highest quality images and maps available. It usually will be necessary to verify decisions made from photo interpretation in the field during field reconnaissance.

Variables used in the models to assess wetland functions were defined and discussed in Chapter 4. Information needed to estimate the variables is collected at various spatial scales. The first three variables (V_{CATCH}, V_{UPUSE}, and $V_{CONNECT}$) are landscape-scale variables that describe conditions in the wetland's catchment or watershed. These variables are evaluated using aerial photographs, maps, and field reconnaissance of the area surrounding the WAA. A walking reconnaissance of the WAA itself is needed to evaluate the fourth variable, $V_{HYDROALT}$. Finally, detailed, site-specific data collected within sample plot(s) or subplots at representative locations within the WAA are needed to estimate V_{CTD}, V_{CTDEN}, and the remaining variables. The data sheets shown in Figure 25 are organized

Headwater Slope Wetland HGM Field Data Sheet

Assessment Team:

Project Name:
Location:
Sampling Date: .... **Plot Identifier:**

Sample variables 1-3 using aerial photography, topographic maps, soil survey maps, etc.

1.	V_{CATCH}	Percent change in the size of the catchment (If there is no water diversion or augmentation in the catchment, percent change = 0) ……………………………………		%
		Size of original catchment = ___________ ha		
		If diversion: Size of current catchment = ___________ ha		
		If augmentation: Size of catchment from which water is being imported = ___________ ha		
2.	V_{UPUSE}	Weighted average runoff score for the catchment ………………………………………..		

Land Use	Soil Group	Runoff Score	Percent (or ha) in Catchment

3.	$V_{CONNECT}$	Percent of wetland perimeter that is connected to suitable habitat …………………		%
		Total length of wetland perimeter = _____________ m		
		Length of wetland perimeter with suitable habitat ≥150 m (492 ft) wide = ___________ m		

Sample variable 4 during onsite field reconnaissance

4.	$V_{HYDROALT}$	Height of obstruction, depth of ditch, or depth of impounded water ……..………		cm

Sample variables 5-11 within one or more representative 0.04-ha (0.1-acre) plot(s) within the WAA
(Use a separate data sheet for each 0.04-ha plot. Report averages across all plots on a separate cover sheet.)

5.	V_{CTD}	Average dbh of canopy trees (measure only if total tree cover is ≥20%) ………...		cm
		List dbh measurements of individual canopy trees (≥10 cm) below:		

Subplot 1		Subplot 2		Subplot 3		Subplot 4	

6.	V_{CTDEN}	Average number of canopy trees per ha (= canopy trees in 0.04-ha plot × 25) …..		/ha
		# of canopy trees in Subplots 1: _________ 2: _________ 3: _________ 4:		
7.	V_{SSC}	Average percent cover of saplings/shrubs (measure only if tree cover is <20%) ...		%
		Subplots 1: _________% 2: __________% 3: _________% 4: _________%		
8.	V_{GVC}	Average percent cover of ground-layer vegetation (measure only if tree and sapling/shrub cover are each <20%) ………………………………………………		%
		Subplots 1: _________% 2: __________% 3: _________% 4: _________%		

Remarks:

Figure 25. Sample field data sheet for Headwater Slope wetlands (Continued)

9.	V_{COMP}	Vegetation Composition (Check dominant species in the tallest stratum. Check all exotics and invasives, including non-dominants, in all strata on plot.)					
Group 1 = 1.0		Group 2 = 0.66		Group 3 (exotics and invasives) = 0.0			
	Magnolia grandiflora		*Acer rubrum*		*Albizia julibrissin*		*Lygodium japonicum*
	Magnolia virginiana		*Liquidambar styraciflua*		*Alternanthera philoxeroides*		*Microstegium vimineum*
	Nyssa biflora		*Liriodendron tulipifera*		*Aster tataricus*		*Panicum repens*
	Persea borbonia		*Nyssa sylvatica*		*Briza minor*		*Pueraria montana*
	Persea palustris		*Quercus laurifolia*		*Cerastium fontanum*		*Sorghum halepense*
	Pinus elliottii		*Quercus nigra*		*Imperata cylindrica*		*Triadica sebifera*
					Ligustrum japonicum		*Verbena brasilienis*
					Ligustrum sinense		
					Lonicera japonica		

10.	$V_{DETRITUS}$	Average percent cover of leaves, sticks, or other organic material ………………		%
		Subplots 1: _________% 2: _________% 3: ________% 4: _________%		
11.	V_{SSOM}	Average Munsell soil color value …………………………………………………		
		Subplots 1: __________ 2: __________ 3: _________ 4:		

Remarks:

Figure 25. (Concluded)

to facilitate data collection at each spatial scale. Instructions for measuring each variable follow.

Landscape-scale variables

Change in Catchment Size (V_{CATCH})

Measure/Units: Percentage change in the effective size of the wetland catchment or basin. Use the following procedure to measure V_{CATCH}:

1. If there are no ditches, drains, or water diversions in the wetland's catchment, and no augmentation of hydrology through interbasin transfers of water, then the percentage change in catchment size is 0 (subindex for V_{CATCH} = 1.0) and the following steps may be skipped. Otherwise, use aerial photographs, topographic maps, or field reconnaissance to delineate the catchment or watershed of the Headwater Slope wetland.
2. Determine the total area of the catchment under natural conditions (i.e., overlooking any diversions or drains that may be present).
3. Determine the existing catchment area by subtracting those portions of the natural catchment from which surface or subsurface water is being diverted away from the wetland. In the case of water transfer into the wetland's catchment from an adjacent basin, determine the area of the basin (or portion of the basin) from which water is being transferred.
4. Use Equation 1 or 2 in Chapter 4, whichever is appropriate, to calculate the percentage change in effective catchment size.
5. Use Figure 18 to determine the subindex score for V_{CATCH}. If the effective size of the catchment is unchanged (i.e., no water diversions), the subindex score is 1.0.

Upland Land Use (V_{UPUSE})

Measure/Units: Weighted average runoff score for the catchment that provides water to the Headwater Slope wetland. Use the following procedure to measure V_{UPUSE}:

1. Use topographic maps or other sources to delineate the existing catchment or watershed of the Headwater Slope wetland. Do not include areas from which water is being diverted away from the wetland; include any adjacent catchment area from which water is being imported into the wetland's catchment (see V_{CATCH}).
2. Use recent aerial photographs or field reconnaissance to determine the land-use categories (Table 6) present in the catchment.
3. Use a local soil survey or onsite soil sampling to determine the soil series that occur in the catchment. Based on information in the soil survey, determine the hydrologic group(s) (i.e., A, B, C, or D) for the soils present in the catchment.

4. Using GIS techniques, aerial photos, or field reconnaissance, determine the percentage of the catchment represented by each combination of land-use category and soil hydrologic group shown in Table 6.
5. Determine the runoff score for each combination of land-use category and soil hydrologic group present in the catchment (Table 6).
6. Determine a weighted (by area) average runoff score for the catchment. An example can be found in Appendix B.
7. Use Figure 16 to determine the subindex score for V_{UPUSE}.

Habitat Connections ($V_{CONNECT}$)

Measure/Units: Percentage of the wetland's perimeter and width that is connected to suitable habitat. Use the following procedure to measure $V_{CONNECT}$:

1. Determine the total length and average width of the wetland perimeter using field reconnaissance, topographic maps, aerial photographs, or GIS techniques.
2. Determine the length of the wetland perimeter that has a suitable habitat buffer at least 10 m (32.8 ft) in width. See Chapter 4 for examples of suitable habitat types.
3. Divide the length of wetland perimeter having suitable buffer width by the total length of the wetland perimeter.
4. Convert to a percentage by multiplying by 100.
5. Use Figure 10 to determine the Connection Index for $V_{CONNECT}$.
6. Multiply the Connection Index by 0.33 if the average perimeter width is $\geq$ 10 m and <30 m (32.8 to 98.4 ft) wide, 0.66 if the average perimeter width is > 30 m and < 150 m (98.4 to 492 ft), or 1.0 if the average perimeter width is $\geq$ 150 m (492 ft) to determine the subindex score for $V_{CONNECT}$.

Wetland-scale variable

Hydrologic alterations ($V_{HYDROALT}$)

Measure/Units: This variable is quantified by the height of any dam, berm, or water-control structure or depth of any ditch located within the wetland, or by the maximum depth of water impounded in the wetland. Use the following procedure to measure $V_{HYDROALT}$:

1. If wetland hydrology is unaltered and there are no obstructions to natural water storage or flow, and there are no ditches or excessive ponding within the wetland, then the height is 0, the subindex score for $V_{HYDROALT}$ is 1.0, and the following steps may be skipped.
2. If wetland hydrology has been altered, identify any permanent obstructions to surface water flow such as dams or road crossings, any ditches that increase drainage, or standing water that covers more than

70 percent of the wetland surface. Natural microtopography or even wheel and tire ruts do not alter the natural hydrology of a Headwater Slope wetland appreciably.

3. Measure the height of the obstruction, depth of the ditch, or depth of ponded water in centimeters from the natural ground surface.
4. Use Figure 12 to determine the subindex score for $V_{HYDROALT}$.

Plot-scale variables

Data on vegetation and soil conditions in Headwater Slope wetlands are collected within one or more 0.04-ha (0.1-acre) sample plot(s), each divided into four equal subplots (Figure 26). Plots are needed to determine the density of trees, if present. They also make the estimation of percentage cover of saplings/shrubs, ground-layer vegetation, and organic litter easier and more accurate. Some vegetation and soil variables are sampled on subplots as a way to determine average conditions when there is variability across the larger plot.

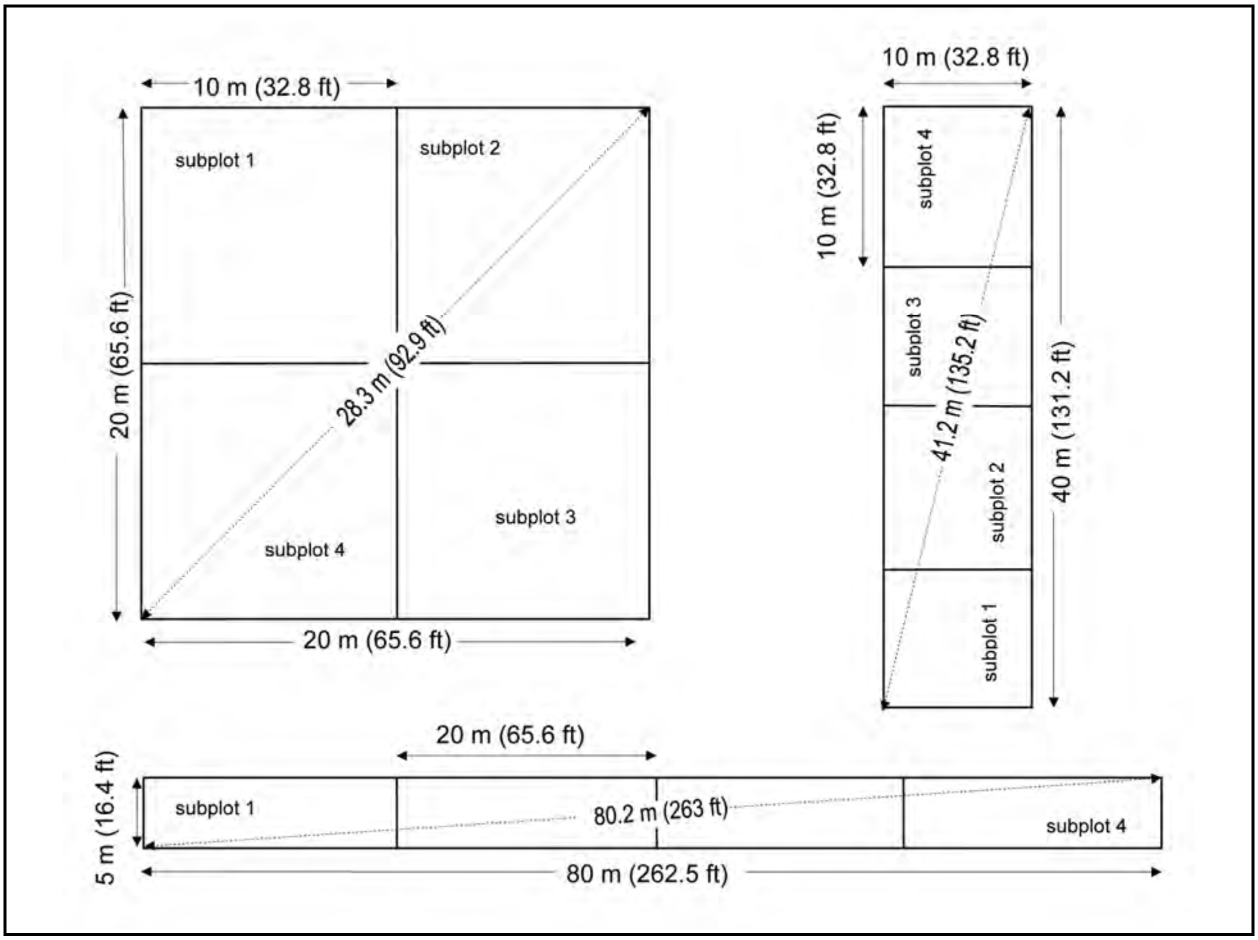

Figure 26. Examples of plot and subplot shapes that equal 0.04 ha (0.1 acre)

The following equipment is needed to establish the sample plot(s) and measure the plot-based variables.

- A 50-m measuring tape, stakes, corner prism (optional), and flagging.
- Plant identification references or keys.
- Soil probe or sharpshooter shovel.

While a 0.04-ha- (0.1-acre-) square plot is fairly easy to lay out, the size and shape of the wetland may require a rectangular plot or some other shape. Figure 26 shows examples of rectangular plots measuring 10×40 m and 5×80 m, which also cover 0.04 ha but may fit better within a narrow, linear wetland. Furthermore, the subplots do not need to be contiguous if separating them would fit better within a meandering drainage. Any combination of plot sizes and shapes that equals 0.04 ha is recommended. If the wetland is smaller than 0.04 ha, the entire wetland may be sampled. In cases where odd-sized plots or the entire wetland are sampled, the area sampled will need to be determined to calculate the density of canopy trees (V_{CTDEN}) in stems per hectare.

Canopy Tree Diameter (V_{CTD})

Measure/Units: Average dbh in cm of all *canopy* trees within a 0.04-ha (0.1-acre) plot. Use the following procedure to measure V_{CTD}:

1. This variable is measured only if the total cover of trees ≥10 cm (4 in.) dbh in the wetland is ≥20 percent. If tree cover is <20 percent, the following steps may be skipped.
2. Measure the dbh (cm) of all *canopy* trees within a 0.04-ha (0.1-acre) plot or, alternatively, within each of four 0.01-ha (0.025-acre) subplots. See Chapter 4 and Figure 6 or the glossary (Appendix A) for the definition of a canopy tree.
3. Calculate the mean canopy tree diameter by summing dbh measurements across subplots and dividing by the total number of trees measured.
4. If multiple 0.04-ha plots are sampled, average the results from all plots.
5. Report the mean canopy tree diameter in centimeters.
6. Use Figure 7 to determine the subindex score for V_{CTD}.

Canopy Tree Density (V_{CTDEN})

Measure/Units: Number of canopy trees (or stems) per hectare. Use the following procedure to measure V_{CTDEN}:

1. Measure this variable only if the total cover of trees ≥10 cm (4 in.) dbh in the wetland is ≥20 percent. If tree cover is <20 percent, the following steps may be skipped.
2. Use the data gathered for V_{CTD} to determine the number of canopy trees in a 0.04-ha (0.1-acre) plot.

3. Convert this result to a per-hectare basis by multiplying by 25 (there are 25 0.04-ha plots in each hectare).
4. If multiple 0.04-ha plots are sampled, average the results from all plots.
5. Report canopy tree density as the number of trees per hectare.
6. Use Figure 8 to determine the subindex score for V_{CTDEN}.

Sapling/Shrub Cover (V_{SSC})

Measure/Units: Average percentage cover of saplings and shrubs. Use the following procedure to measure V_{SSC}:

1. Measure this variable only if total tree cover is <20 percent and cover of sapling/shrubs is $\geq$20 percent. See Chapter 4 or Appendix A for the definition of saplings and shrubs.
2. Visually estimate the percentage cover of saplings/shrubs within a 0.04-ha (0.1-acre) plot or, alternatively, within each of the four 0.01-ha (0.025-acre) subplots. If necessary, average the results across subplots.
3. Average the percentage cover estimates if more than one 0.04-ha plot is sampled.
4. Report the average sapling/shrub cover as a percentage.
5. Use Figure 13 to determine the subindex score for V_{SSC}.

Ground Vegetation Cover (V_{GVC})

Measure/Units: Average percentage cover of ground-layer vegetation. Use the following procedure to measure V_{GVC}:

1. Measure this variable only if tree and sapling/shrub cover are each <20 percent. See Chapter 4 or Appendix A for the definition of ground-layer vegetation.
2. Visually estimate the percentage cover of ground-layer vegetation within a 0.04-ha (0.1-acre) plot or, alternatively, within each of the four 0.01-ha (0.025-acre) subplots. If necessary, average the results across subplots.
3. Average the percentage cover estimates if more than one 0.04-ha plot is sampled.
4. Report ground vegetation cover as a percent.
5. Use Figure 9 to determine the subindex score for V_{GVC}.

Vegetation Composition and Diversity (V_{COMP})

Measure/Units: An index based on the species composition and number of dominant species in the uppermost stratum of the wetland's vegetation. Use the following procedure to measure V_{COMP}:

1. If total tree cover is $\geq$20 percent, then V_{COMP} is determined for the tree stratum. If tree cover is <20 percent and sapling/shrub cover is $\geq$20 percent, then V_{COMP} is determined for the sapling/shrub stratum. If tree cover and sapling/shrub cover are both <20 percent, then V_{COMP} is determined for the ground layer, even if the ground layer has <20 percent vegetation cover.
2. Use the "50/20 rule" (Figure 17) to identify the dominant species in the appropriate vegetation stratum. For sites containing a tree stratum, be sure to consider all trees $\geq$10 cm (4 in.) dbh and not just "canopy" trees.
3. On the data form, place a check beside each dominant species that appears in either Group 1 or 2 (Table 7). If a dominant species is not listed but is a species native to the reference domain, it can be added to Group 2 using the blanks provided. For exotic and invasive species in the reference domain (Group 3), check all species encountered on the plot without regard to dominance or stratum. Other exotic and invasive species can be added using the blanks provided and should be treated as Group 3 species. The data form does not list herbaceous plants because of the potentially very long list. Assign all native, noninvasive herb species to Group 1. Invasive and exotic herb species that occur in wetlands in the reference domain should be listed in Group 3.
4. Using the checked dominants in Groups 1 and 2 and the checked exotic or invasive species in Group 3, calculate an initial quality index (Q) using the following formula:

   Q = [(1.0 × *number of checked dominants in Group 1*) + (0.66 × *number of checked dominants in Group 2*) + (0.0 × *number of checked species in Group 3*)] / *total number of checked species in all groups*

5. Calculate an adjusted quality index (R) that takes species richness into consideration. Multiply Q by one of the following constants:
   - *a.* If four or more species from Groups 1 or 2 occur as dominants, multiply by 1.0 (i.e., R = Q × 1.0).
   - *b.* If three species from Groups 1 or 2 occur as dominants, multiply by 0.75 (i.e., R = Q × 0.75).
   - *c.* If two species from Groups 1 or 2 occur as dominants, multiply by 0.50 (i.e., R = Q × 0.50).
   - *d.* If one species from Groups 1 or 2 occurs as a dominant, multiply by 0.25 (i.e., R = Q × 0.25).
   - *e.* If no species from Groups 1 or 2 occur as dominants, multiply by 0.0 (i.e., R = Q × 0.0).

   (In a small assessment area (e.g., <0.25 ha), it is possible that fewer than four species may be dominant, even in a high-quality community. In such cases, at the discretion of the user, Q can be multiplied by 1.0, even if as few as two species are dominant.)
6. Calculate the square root of R. This is the subindex for vegetation composition and diversity (V_{COMP}).

Soil Detritus ($V_{DETRITUS}$)

Measure/Units: Average percentage of the ground surface covered by leaves, sticks, or other organic material. Use the following procedure to measure $V_{DETRITUS}$:

1. Visually estimate the percentage cover of leaves, sticks, or other organic material within each 0.04-ha (0.1-acre) plot or, alternatively, within each of the four 0.01-ha (0.025-acre) subplots. See Chapter 4 or Appendix A for the definition of detritus. If necessary, average the results across subplots.
2. Average the percentage cover estimates if more than one 0.04-ha plot is sampled.
3. Report the average cover of detritus as a percentage.
4. Use Figure 15 to determine the subindex score for $V_{DETRITUS}$.

Surface Soil Organic Matter (V_{SSOM})

Measure/Units: Average Munsell® soil color value. Use the following procedure to measure V_{SSOM}:

1. At four representative locations within each 0.04-ha (0.1-acre) plot, or at one representative location in each 0.01-ha (0.025-acre) subplot, use a soil probe or shovel and excavate the soil to a depth of about 15 cm (6 in.). Determine the color value of the surface soil layer, below the detrital layer, to the nearest color chip using a Munsell soil color chart.
2. Average all of the Munsell soil color values across sampling points.
3. Report surface soil organic matter as a number between 2 and 8.
4. Use Table 5 to determine the subindex score for V_{SSOM}.

Analyze the Data

The first step in analyzing the field data is to transform the field measure of each assessment variable into a variable subindex on a scale of 0 to 1.0. This can be done using the graphs and tables in Chapter 4. The second step is to insert the variable subindices into the equations for each assessment model and calculate the FCIs using the relationships defined in the models. Again, this can be done manually or automatically using a spreadsheet. Finally, multiply the FCI for each function by the total size of the WAA to calculate the number of Functional Capacity Units (FCUs) for each function (Smith et al. 1995).

Apply Assessment Results

Once the assessment and analysis phases are complete, the results can be used to compare the level(s) of function in the same WAA at different points in time or in different WAAs at the same point in time. The information can be used to address the specific objectives identified at the beginning of the study, such as

(a) determining project impacts, (b) comparing project alternatives, (c) determining mitigation requirements, and (d) evaluating mitigation success.

To evaluate project-related impacts, at least two assessments will generally be needed. The first assesses the number of FCUs provided by the site in its pre-project condition. The second assesses the number of FCUs provided by the site in a post-project state, based on proposed project plans and the associated changes to each of the model variables. The difference between pre-project and post-project conditions, expressed in numbers of FCUs, represents the potential loss of functional capacity due to project impacts. Similarly, in a mitigation scenario, the difference between the current condition and future condition of a site, with mitigation actions implemented and successfully completed, represents the potential gain in functional capacity as a result of restoration activities. However, since the mitigation project is unlikely to become fully functional immediately upon completion, a time lag must be incorporated in the analysis to account for the time necessary for the mitigation site to achieve full functional development.

For more information on the calculation of FCUs and their use in project assessments, see Smith et al. (1995). Spreadsheets that can be used to help evaluate project impacts and estimate mitigation requirements are available on the web at http://el.erdc.usace.army.mil/wetlands/datanal.html. The spreadsheets were developed by Frank Hanrahan based on concepts presented by the U.S. Fish and Wildlife Service (1980) and King and Adler (1992).

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Appendix A
Glossary

Assessment Model: A model that defines the relationship between ecosystem and landscape scale variables and functional capacity of a wetland. The model is developed and calibrated using reference wetlands from a reference domain.

Assessment Objective: The reason an assessment of wetland functions is conducted. Assessment objectives normally fall into one of three categories: documenting existing conditions, comparing different wetlands at the same point in time (e.g. alternatives analysis), and comparing the same wetland at different points in time (e.g., impacts analysis or mitigation success).

Assessment Team (A-Team): An interdisciplinary group of regional and local scientists responsible for classification of wetlands within a region, identification of reference wetlands, construction of assessment models, definition of reference standards, and calibration of assessment models.

Canopy Tree: Self-supporting woody plants ≥10 cm (4 in.) dbh, whose crowns compose the uppermost stratum of the vegetation. Canopy trees are not immediately overtopped by taller trees and would be clearly seen by an airborne observer (Figure 6).

Catchment: The geographic area where surface water would flow or run off into the headwater wetland.

Curve number: A dimensionless parameter that varies from 0 to 100 and provides an indication of runoff potential.

Detritus: The soil layer dominated by partially decomposed but still recognizable organic material, such as leaves, sticks, needles, flowers, fruits, insect frass, dead moss, or detached lichens on the surface of the ground. This material would classify as fibric or hemic material (peat or mucky peat).

Diameter at Breast Height (DBH): Tree diameter measured at 1.4 m (55 in.) above the ground.

Direct impacts: Project impacts that result from direct physical alteration of a wetland, such as the placement of dredge or fill.

Direct measure: A quantitative measure of an assessment model variable.

Exotics: See Invasive **species.**

Facultative species (FAC): A plant species equally likely to occur in wetlands or non-wetlands (estimated probability of occurrence in wetlands 34 to 66 percent).

Facultative upland species (FACU): A plant species that usually occurs in non-wetlands but sometimes is found in wetlands (estimated probability of occurrence in wetlands 1 to 33 percent).

Facultative wetland species (FACW): A plant species that usually occurs in wetlands (estimated probability 67 to 99 percent), but sometimes is found in non-wetlands.

Functional assessment: The process by which the capacity of a wetland to perform a function is measured. This approach measures capacity using an assessment model to determine a Functional Capacity Index.

Functional Capacity Index (FCI): An index of the capacity of a wetland to perform a function relative to other wetlands in a regional wetland subclass. Functional Capacity Indices are by definition scaled from 0.0 to 1.0. An index of 1.0 indicates the wetland is performing a function at the highest sustainable functional capacity, the level equivalent to a wetland under reference standard conditions in a reference domain. An index of 0.0 indicates the wetland does not perform the function at a measurable level, and will not recover the capacity to perform the function through natural processes.

Functional capacity: The rate or magnitude at which a wetland ecosystem performs a function. Functional capacity is dictated by characteristics of the wetland ecosystem and the surrounding landscape, and interaction between the two.

Ground layer: The layer of vegetation consisting of all herbaceous plants, regardless of height, and woody plants less than 1 m (39 in.) tall.

Highest sustainable functional capacity: The level of functional capacity achieved across the suite of functions performed by a wetland under reference standard conditions in a reference domain. This approach assumes the highest sustainable functional capacity is achieved when a wetland ecosystem and the surrounding area are undisturbed.

Highest sustainable functional capacity: The level of functional capacity achieved across the suite of functions by a wetland under reference standard conditions in a reference domain. This approach assumes that the highest sustainable functional capacity is achieved when a wetland ecosystem and the surrounding area are undisturbed.

Hydrogeomorphic unit: Hydrogeomorphic units are areas within a wetland assessment area that are relatively homogeneous with respect to ecosystem scale characteristics such as microtopography, soil type, vegetative communities, or other factors that influence function. Hydrogeomorphic units may be the result of natural or anthropogenic processes.

Hydrogeomorphic wetland class: The highest level in the hydrogeomorphic wetland classification. There are five basic hydrogeomorphic wetland classes: depression, riverine, slope, fringe, and flat.

Hydrologic Soil Group: Soils are classified by the Natural Resources Conservation Service into four groups based on the soil's runoff potential: A, B, C, and D. Soils in group A have the least runoff potential, and soils in group D have the highest runoff potential.

Hydroperiod: The annual duration of flooding (in days per year) at a specific point in a wetland.

Indicator: Observable characteristics that correspond to identifiable variable conditions in a wetland or the surrounding landscape.

Indirect impacts: Impacts resulting from a project that occur concurrently, or at some time in the future, away from the point of direct impact. For example, indirect impacts of a project on wildlife can result from an increase in the level of activity in adjacent, newly developed areas, even though the wetland is not physically altered by direct impacts.

Indirect measure: A qualitative measure of an assessment model variable that corresponds to an identifiable variable condition.

Invasive species: Generally, exotic species without natural controls that out-compete native species.

Jurisdictional wetland: Areas that meet the soil, vegetation, and hydrologic criteria described in the "Corps of Engineers Wetlands Delineation Manual" (Environmental Laboratory 1987)[1] or its successor. Not all wetlands are regulated under Section 404.

Mitigation plan: A plan for replacing lost functional capacity resulting from project impacts.

Mitigation wetland: A restored or created wetland that serves to replace functional capacity lost as a result of project impacts.

Mitigation: Restoration or creation of a wetland to replace functional capacity that is lost as a result of project impacts.

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[1] References cited in this Appendix are included in the References section at the end of the main text.

Model variable: A characteristic of the wetland ecosystem or surrounding landscape that influences the capacity of a wetland ecosystem to perform a function.

Obligate upland (UPL): A plant species that almost always occurs in non-wetlands under natural conditions (estimated probability of occurrence in wetlands <1 percent).

Obligate wetland (OBL): A plant species that almost always occurs in wetlands (estimated probability >99 percent) under natural conditions.

Organic matter: Plant and animal residue in the soil in various stages of decomposition.

Organic soil material: Soil material that is saturated with water for long periods or artificially drained and, excluding live roots, has an organic carbon content of 18 percent or more with 60 percent or more clay, or 12 percent or more organic carbon with 0 percent clay. Soils with an intermediate amount of clay have an intermediate amount of organic carbon. If the soil is never saturated for more than a few days, it contains 20 percent or more organic carbon.

Oxidation: The loss of one or more electrons by an ion or molecule.

Partial wetland assessment area (PWAA): A portion of a WAA that is identified a priori, or while applying the assessment procedure to an area relatively homogeneous and different from the rest of the WAA with respect to one or more variables. Differences may be natural or result from anthropogenic disturbance.

Project alternative(s): Different ways in which a given project can be done. Alternatives may vary in terms of project location, design, method of construction, amount of fill required, and other ways.

Project area: The area that encompasses all activities related to an ongoing or proposed project.

Project target: The level of functioning identified for a restoration or creation project. Conditions specified for the functioning are used to judge whether a project reaches the target and is developing toward site capacity.

Red flag features: Features of a wetland or surrounding landscape to which special recognition or protection is assigned on the basis of objective criteria. The recognition or protection may occur at a Federal, State, regional, or local level and may be official or unofficial.

Reference domain: All wetlands within a defined geographic area that belong to a single regional wetland subclass.

Reference standards: Conditions exhibited by a group of reference wetlands that correspond to the highest level of functioning (highest sustainable capacity) across the suite of functions of the regional wetland subclass. By definition, highest levels of functioning are assigned an index of 1.0.

Reference wetlands: Wetland sites that encompass the variability of a regional wetland subclass in a reference domain. Reference wetlands are used to establish the range of conditions for construction and calibration of functional indices and to establish reference standards.

Region: A geographic area that is relatively homogeneous with respect to large-scale factors such as climate and geology that may influence how wetlands function.

Regional wetland subclass: Regional hydrogeomorphic wetland classes that can be identified based on landscape and ecosystem scale factors. There may be more than one regional wetland subclass for each of the hydrogeomorphic wetland classes that occur in a region, or there may be only one.

Runoff: Water flowing on the surface either by overland sheet flow or by channel flow in rills, gullies, streams, or rivers.

Sapling/shrub layer: For the purposes of this guidebook, the vegetation layer consisting of self-supporting woody plants greater than 1 m (39 in.) in height but less than 10 cm (4 in.) in diameter at breast height.

Seasonal high water table: The shallowest depth to free water that stands in an unlined borehole or where the soil moisture tension is zero for a significant period (for more than a few weeks).

Site potential: The highest level of functioning possible, given local constraints of disturbance history, land use, or other factors. Site capacity may be equal to or less than levels of functioning established by reference standards for the reference domain, and it may be equal to or less than the functional capacity of a wetland ecosystem.

Soil surface: The soil surface is the top of the mineral soil; or, for soils with an O horizon, the soil surface is the top of the part of the O horizon that is at least slightly decomposed. Fresh leaf or needle fall that has not undergone observable decomposition is excluded from soil and may be described separately (Carlisle 2000).

Value of wetland function: The relative importance of wetland function or functions to an individual or group.

Variable: An attribute or characteristic of a wetland ecosystem or the surrounding landscape that influences the capacity of the wetland to perform a function.

Variable condition: The condition of a variable as determined through quantitative or qualitative measure.

Variable index: A measure of how an assessment model variable in a wetland compares to the reference standards of a regional wetland subclass in a reference domain.

Watershed: The geographic area that contributes surface runoff to a common point, known as the watershed outlet.

Wetland assessment area (WAA): The wetland area to which results of an assessment are applied.

Wetland ecosystems: In Section 404 of the Clean Water Act, "…areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (Corps Regulation 33 CFR 328.3 and EPA Regulations 40 CFR 230.3). In a more general sense, wetland ecosystems are three-dimensional segments of the natural world where the presence of water at or near the surface creates conditions leading to the development of redoximorphic soil conditions and the presence of a flora and fauna adapted to the permanently or periodically flooded or saturated conditions.

Wetland functions: The normal activities or actions that occur in wetland ecosystems, or simply, the things that wetlands do. Wetland functions result directly from the characteristics of a wetland ecosystem and the surrounding landscape and their interaction.

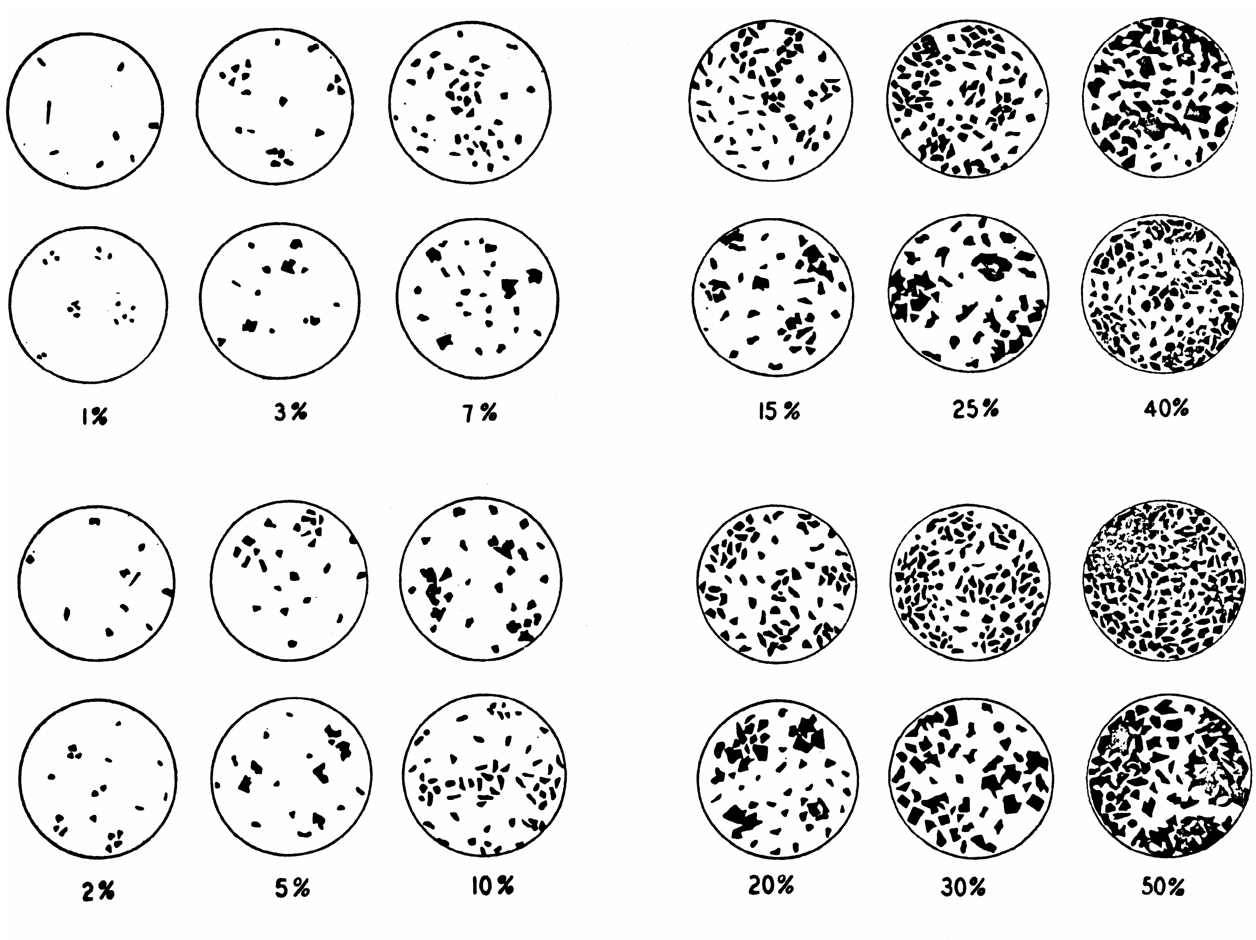
Wetland restoration: The process of restoring wetland function in a degraded wetland. Restoration is typically done as mitigation.

Wetland: In Section 404 of the Clean Water Act, "…areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." The presence of water at or near the surface creates conditions leading to the development of redoximorphic soil conditions, and the presence of a flora and fauna adapted to the permanently or periodically flooded or saturated conditions.

Appendix B Supplementary Information on Model Variables

This appendix contains the following information:

Comparison Charts for Visual Estimation of Foliage Cover[1]



[1] Developed by Richard D. Terry and George V. Chilingar. Published by the Society of Economic Paleontologists in its *Journal of Sedimentary Petrology* 25(3): 229-234, September 1955.

Table B1
Hydrologic Soil Groups for Soils in the Reference Domain

Soil Component	Hydrologic Group	Soil Component	Hydrologic Group	Soil Component	Hydrologic Group	Soil Component	Hydrologic Group
Alaga	A	Deerford	D	Lorman	D	Prim	D
Annemaine	C	Dogue	C	Lucedale	B	Psamments	D
Arat	D	Dorovan	D	Lucy	A	Quitman	C
Arkabutla	C	Duckston	A/D	Luverne	C	Rayburn	D
Arundel	C	Escambia	C	Malbis	B	Riverview	B
Atmore	B/D	Esto	B	Mantachie	C	Robertsdale	C
Axis	D	Eustis	A	Mashulaville	B/D	RockOutcrop	D
Bama	B	Eutrudepts	D	Maubila	C	Rosebloom	D
Basin	C	Falkner	C	Maurepas	D	Ruston	B
Bassfield	B	Flomaton	A	Maytag	D	Saffell	B
Baxterville	B	Fluvaquents	D	Mccrory	D	Saucier	C
Bayou	D	Freest	C	Mclaurin	B	Savannah	C
Beaches	D	Fripp	A	Mooreville	C	Shubuta	C
Beatrice	D	Grady	D	Myatt	D	Smithdale	B
Beauregard	C	Greenville	B	Nahunta	C	Smithton	D
Benndale	B	Guyton	D	Newhan	A	St.Lucie	A
Bethera	D	Halso	D	Notcher	B	Stough	C
Bibb	D	Handsboro	D	Nugent	A	Suffolk	B
Bigbee	A	Harleston	C	Ochlockonee	B	Suggsville	D
Bohicket	D	Heidel	B	Ocilla	C	Sulfaquepts	D
Boswell	D	Hyde	B/D	Okeelala	B	Sumter	C
Boykin	B	Ichusa	D	Okolona	D	Susquehanna	D
Brantley	C	Irvington	C	Oktibbeha	D	Sweatman	C
Cadeville	D	Iuka	C	Olla	C	Toxey	D
Cahaba	B	Izagora	C	Ora	C	Trebloc	D
Cantuche	D	Jedburg	C	Osier	A/D	Troup	A
Cascilla	B	Jena	B	Ouachita	C	Udorthents	C
Catalpa	C	Johns	C	Pactolus	A	Una	D
Chastain	D	Johnston	D	Pamlico	D	Urbo	D
Chenneby	C	Kinston	D	Paxville	D	Vancleave	C
Chrysler	C	Lafitte	D	Pelham	D	Wadley	A
CoastalBeach	D	Lakeland	A	Petal	C	Wagram	A
Columbus	C	Latonia	B	Pheba	C	Wahee	D
Conecuh	D	Leaf	D	Pits	B	Watsonia	D
Congaree	B	Leeper	D	Plummer	B/D	Yonges	D
Corolla	D	Lenoir	D	Poarch	B		
Croatan	D	Leon	D	Ponzer	D		
Daleville	D	Levy	D	Prentiss	C		

Table B2
Plant Species Found During Data Collection on Reference Wetlands

Scientific Name*	Common name*	Scientific Name*	Common name*
Albizia julibrissin	silktree	*Ligusticum canadense*	Canadian licorice-root
Alternanthera philoxeroides	alligatorweed	*Liquidambar styraciflua*	sweetgum
Aster tataricus	tatarian aster	*Liriodendron tulipifera*	tuliptree
Briza minor	little quakinggrass	*Listera australis*	southern twayblade
Cerastium fontanum	common mouse-ear chickweed	*Lyonia lucida*	feterbush lyonia
Ligustrum sinense	Chinese privet	*Magnolia grandiflora*	southern magnolia
Lonicera japonica	Japanese honeysuckle	*Magnolia virginiana*	sweetbay
Lygodium japonicum	Japanese climbing fern	*Mitchella repens*	partridgeberry
Microstegium vimineum	Nepalese browntop	*Morella caroliniensis*	southern bayberry
Pueraria montana	kudzu	*Morella cerifera*	wax myrtle
Sorghum halepense	Johnsongrass	*Morella inodora*	scentless bayberry
Triadica sebifera	small tallowtree	*Nyssa biflora*	swamp tupelo
Verbena brasiliensis	Brazilian vervain	*Nyssa sylvatica*	blackgum
Acer rubrum	red maple	*Osmanthus americanus*	devilwood
Apteria aphylla	nodding nixie	*Osmunda cinnamomea*	cinnamon fern
Arundinaria gigantea	giant cane	*Osmunda regalis*	royal fern
Berchemia scandens	Alabama supplejack	*Oxydendrum arboreum*	sourwood
Bignonia capreolata	crossvine	*Panicum virgatum*	switchgrass
Callicarpa americana	American beautyberry	*Persea borbonia*	redbay
Calystegia sepium	hedge false bindweed	*Persea humilis*	silk bay
Campsis radicans	trumpet creeper	*Persea palustris*	swamp bay
Carex glaucescens	southern waxy sedge	*Pinus elliottii*	slash pine
Carpinus caroliniana	American hornbeam	*Pinus palustris*	longleaf pine
Carya glabra	pignut hickory	*Pinus taeda*	loblolly pine
Chasmanthium sessiliflorum	longleaf woodoats	*Potentilla simplex*	common cinquefoil
Clethra alnifolia	coastal sweetpepperbush	*Quercus hemisphaerica*	Darlington oak
Cliftonia monophylla	buckwheat tree	*Quercus laurifolia*	laurel oak
Crinum americanum	seven sisters	*Quercus michauxii*	swamp chestnut oak
Cyperus virens	green flatsedge	*Quercus nigra*	water oak
Cyrilla racemiflora	swamp titi	*Rhus copallinum*	winged sumac
Decumaria barbara	woodvamp	*Rubus trivialis*	southern dewberry
Diospyros virginiana	common persimmon	*Sabal minor*	dwarf palmetto
Drosera brevifolia	dwarf sundew	*Sarracenia alata*	yellow trumpets
Epidendrum conopseum	green fly orchid	*Sarracenia leucophylla*	crimson pitcherplant
Euonymus americana	strawberry bush	*Sarracenia purpurea*	purple pitcherplant
Eupatorium capillifolium	dogfennel	*Saururus cernuus*	lizard's tail
Eupatorium fistulosum	trumpetweed	*Scapania paludicola*	liverwort
Eupatorium perfoliatum	common boneset	*Smilax bona-nox*	saw greenbrier
Fagus grandifolia	American beech	*Smilax laurifolia*	laurel greenbrier
Hamamelis virginiana	American witchhazel	*Smilax tanoides*	bristly greenbrier
Hydrocotyle bonariensis	largeleaf pennywort	*Thelypteris kunthii*	Kunth's maiden fern
Hypericum hypericoides	St. Andrew's cross	*Tillandsia usneoides*	Spanish moss
Ilex coriacea	large gallberry	*Toxicodendron radicans*	poison ivy
Ilex glabra	inkberry	*Toxicodendron vernix*	poison sumac
Ilex opaca	American holly	*Vaccinium elliotti*	Elliott's blueberry
Ilex verticillata	common winterberry	*Vaccinium stamineum*	deerberry
Ilex vomitoria	yaupon	*Viburnum dentatum*	southern arrowwood
Illicium floridanum	Florida anisetree	*Viburnum nudum*	possumhaw
Iris virginica	Virginia iris	*Viola ×primulifolia*	bog white violet
Itea virginica	Virginia sweetspire	*Vitis labrusca*	fox grape
Juncus marginatus	grassleaf rush	*Vitis rotundifolia*	muscadine
Juniperus virginiana	eastern redcedar	*Woodwardia areolata*	netted chainfern
Leucothoe axillaris	coastal doghobble	*Woodwardia virginica*	Virginia chainfern

*Scientific and common names according to USDA Plants Database.

Weighted Average Method for Determining V_{UPUSE}

The following example shows how to estimate the weighted average runoff score for V_{UPUSE}:

Identify the different land-use types within the catchment of the WAA using recent aerial photography (Figure B1). Estimate the percentage of the catchment in each land-use type. Verify during onsite reconnaissance.

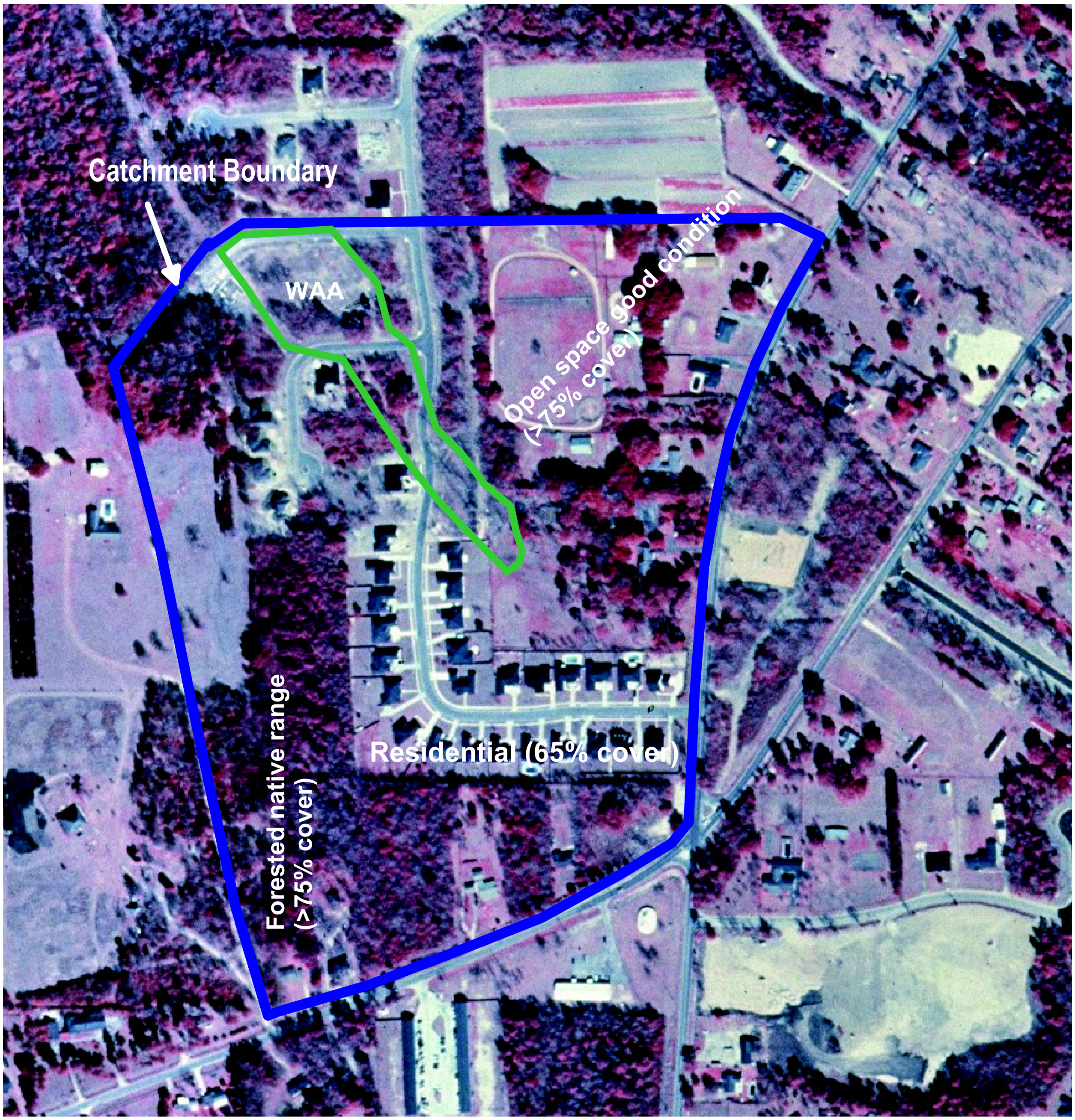


Figure B1. Aerial photograph illustrating the cover types found within the catchment of a wetland

Identify the soils within the catchment and determine the hydrologic soil group (A, B, C, or D) based on the soil series identified for the area in the appropriate soil survey. In this example, all of the soils are in hydrologic soil group D.

Table B3
V_{UPUSE} Example

Cover Type	Percent of Catchment	Runoff Curve Numbers
Forest and native range (>75% ground cover)	75	77
Residential (65% cover)	10	92
Open space good condition (>75% cover)	15	80
Total	100	

Determine the runoff curve number for each combination of land-use and hydrologic soil group present (Table B3).

Multiply the runoff curve number by the percentage of the catchment, sum these products across the entire catchment, and divide by 100.

For this example, the weighted average runoff score is:

$$\left[\frac{(77\times 75)+(92\times 10)+(80\times 15)}{100}\right]=78.95 \tag{B1}$$

Using the graph for V_{UPUSE}, determine the variable subindex score that corresponds to a runoff score of 78.95 (round to 79) (Figure 16). The variable subindex score for this example is 0.44.

Determining the Subindex Score for Surface Soil Organic Matter (V_{SSOM}) by Averaging the Soil Color Values from all Subplots

Because of inaccurate color reproduction, do not use this page to determine soil colors in the field.

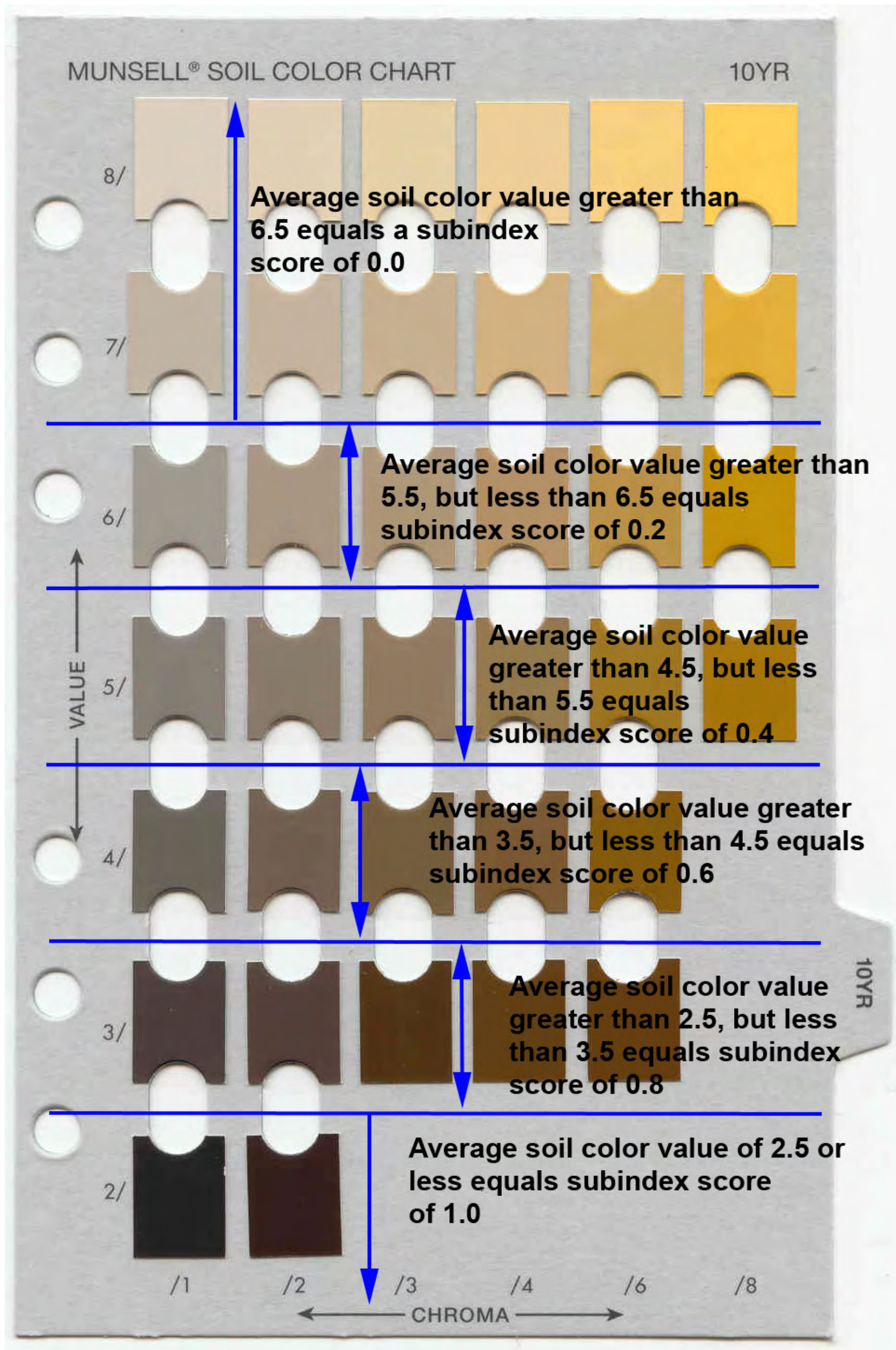


Figure B2. Background image from the Munsell Soil Color Charts and courtesy of Munsell Color Services Lab, now part of X-Rite, Inc.

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14. ABSTRACT

The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence. This Regional Guidebook (a) characterizes the Headwater Slope wetlands in southern Mississippi and Alabama, (b) describes and provides the rationale used to select functions for the Headwater Slope wetland subclass, (c) describes model variables and metrics, (d) describes the development of assessment models, (e) provides data from reference wetlands and documents their use in calibrating model variables and assessment models, and (f) outlines protocols for applying the functional indices to the assessment of wetland functions.

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